

Lake and Wetland Monitoring Program

2002 Annual Report

By

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Executive Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 37 Kansas lakes during 2002. Eight of the lakes surveyed were large federal impoundments, 10 were State Fishing Lakes (SFLs), two were units within the Mined Land Lakes Recreation Area, 14 were city and county lakes, and two were small lakes in the Cimarron National Grasslands. The remaining lake, Empire Lake, is owned by Empire Electric. Empire Lake is not a permanent site in the statewide monitoring network, but was surveyed as part of ongoing investigations concerning the impacts of mining activities in southeast Kansas. The two lakes in the Mined Land Lakes Recreation Area are also not permanent sites in the statewide monitoring network. These two lake units were surveyed at the request of KDHE's Bureau of Environmental Remediation in regards to one of their regulated facilities and perchlorate contamination.

Of the 37 lakes surveyed, 65% indicated trophic state conditions comparable to their historic mean water quality conditions. Another 22% indicated improved water quality conditions, over mean historic condition, as evidenced by a lowered lake trophic state. The remaining 13% indicated degraded water quality, over historic mean condition, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 43% of the lakes surveyed during 2002. Nitrogen was identified as the primary limiting factor in 19% of the lakes, while another 5% were identified as primarily light limited. The remaining 33% appeared limited by combinations of nutrients or nutrients and light availability (11%), iron limitation (5%), hydrologic flushing rate (3%), or competition with the macrophyte community (3%). Four lakes (11%) had limiting factors at the time of the surveys that could not be fully ascertained.

There were a total of 224 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2002. Of these 224 exceedences, 38% pertained to the aquatic life use and 62% concerned consumptive and recreational uses. Fully 73% involved uses previously designated in the Kansas Surface Water Register. Approximately 27% were for uses that had not been formally designated or verified by use attainability analyses.

Twenty-one lakes (62% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2002. Atrazine, or its degradation byproduct deethylatrazine, was detected in all 21 of these waterbodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. Owing in large part to reduced runoff and inflow during the current multiple year drought, no lake during 2002 exceeded the water supply criterion for atrazine. A total of four different pesticides, and one pesticide degradation byproduct, were found in lakes during 2002. An increase was noted, during 2002, in the frequency and magnitude of acetochlor detections. This herbicide is a replacement for atrazine, and may represent a future concern for our waters.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, determining regional and time trends for those impoundments, and identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake was reduced to a single station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 120 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The network remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in the identification and control of taste and odor problems in finished drinking water that result from pollution, algae blooms, and natural ecological processes.

Overview of the 2002 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 37 Kansas lakes during 2002. Eight of these lakes are large federal impoundments last sampled in 1999 or as part of special projects, 10 are State Fishing Lakes (SFLs), 14 are city/county lakes (CLs and Co. lakes, respectively), two are small lakes located on the Cimarron National Grasslands refuge, two were units in the Mined Land Lakes Recreation Area, and one is owned by Empire Electric. Twenty of the 37 lakes (54%) serve as either primary or back-up municipal and/or industrial water supplies. Empire Lake is not a permanent site within the statewide monitoring network, but was sampled in 2002 as part of ongoing investigations into mining impacts in southeastern Kansas. Likewise, the two lake units in the Mined Land Lakes Recreation Area are not permanent sites in the statewide monitoring network. These two lake units were investigated at the request of KDHE's Bureau of Environmental Remediation, as part of an investigation into one of their regulated facilities and perchlorate contamination.

General information on the lakes surveyed during 2002 is compiled in Table 1. Figure 1 depicts the locations of the lakes surveyed in 2002. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. Additionally, a total of 11 lakes, streams, and ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Created lakes are usually termed “reservoirs” or “impoundments,” depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed “ponds” based on arbitrary surface area criteria. To provide consistency, this report uses the term “lake” to describe all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington has jurisdiction over two larger lakes. The older lake is referred to as Herington City Lake while the newer one is called Herington Reservoir in order to distinguish it from its sister waterbody.

METHODS

Yearly Selection of Monitored Sites

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is normally sampled only once during a three year period of rotation. Up to 30 smaller lakes are sampled each year in addition to that year’s block of eight federal lakes. These smaller lakes are chosen based on three considerations: 1) Are there recent data available (within the last 3-4 years) from KDHE or other programs?; 2) Is the lake showing indications of pollution that require enhanced monitoring?; or 3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as ecoregional reference sites.

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as Station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of basic inorganic chemistry (major cations and anions), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, total organic carbon, and total and ortho phosphorus), and total recoverable metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5 to 1.0 meters above the lake substrate for determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate fecal coliform bacteria samples, are collected at 0.5 meters depth at the primary sampling point (KDHE, 2000).

At each lake, measurements are made at Station 1 for temperature and dissolved oxygen profiles, field pH, photosynthetically active radiation (PAR) extinction, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE quality assurance/quality control protocols (KDHE, 2000). Field measurements, chlorophyll-a analyses, and algal taxonomic

determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KHEL) (KDHE, 1995).

Table 1. General information pertaining to lakes surveyed during 2002.

Lake	Basin	Authority	Water Supply	Last Survey
Cedar Creek Lake	Marais des Cygnes	City	yes	1998
Centralia Lake	Kansas/Lower Republican	City	yes	1998
Cheney Lake	Lower Arkansas	Federal	yes	1999
Cimarron Lake ^s	Cimarron	Federal	no	1999
Clark Co. SFL	Cimarron	State	yes	1999
Concannon SFL	Upper Arkansas	State	no	1999
Council Grove City Lake	Neosho	City	yes	1998
Council Grove Lake	Neosho	Federal	yes	1999
Douglas Co. SFL	Kansas/Lower Republican	State	no	1998
El Dorado Lake	Walnut	Federal	yes	1999
Empire Lake	Neosho	Utility	no	1994
Ford County Lake	Upper Arkansas	County	no	1999
Gardner City Lake	Kansas/Lower Republican	City	yes	1998
Geary Co. SFL	Smoky Hill/Saline	State	no	1998
Goodman SFL	Upper Arkansas	State	no	1999
Harvey Co. East Lake	Walnut	County	no	1998
Hillsdale Lake	Marais des Cygnes	Federal	yes	2001
John Redmond Lake	Neosho	Federal	yes	1999
Lake Coldwater	Cimarron	City	yes	1999
Lake Crawford	Marais des Cygnes	State	no	1998
Lake Meade SFL	Cimarron	State	no	2001
Lake Scott SFL	Smoky Hill/Saline	State	no	1999
Lyon Co. SFL	Marais des Cygnes	State	no	1998
Madison City Lake	Verdigris	City	yes	1998
Marion Lake	Neosho	Federal	yes	1999

Lake	Basin	Authority	Water Supply	Last Survey
Melvorn Lake	Marais des Cygnes	Federal	yes	2000
Mined Land Lake 22	Neosho	State	no	2002
Mined Land Lake 23	Neosho	State	no	2002
Mission Lake	Kansas/Lower Republican	City	yes	1998
Moline City Lake #2	Verdigris	City	yes	1998
Olpe City Lake	Neosho	City	no	1998
Point of Rocks Lake ^s	Cimarron	Federal	no	1999
Pomona Lake	Marais des Cygnes	Federal	yes	2000
Sedan North Lake	Verdigris	City	yes	1998
St. Jacob's Well	Cimarron	State	no	2000
Thayer New Lake	Verdigris	City	yes	1998
Yates Center Lake	Verdigris	City	yes	1998

\$ = These lakes have been known by different names until 2002, when signs were found posted at the lakes with their actual designations. In previous reports, Cimarron Lake was known as "Moss Lake (Central)" while Point of Rocks Lake was known as "Moss Lake (West)."

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and mapping of 10 to 20 sampling points, depending on total surface area and lake morphometry, distributed on a field map in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations at each station, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Specimens that cannot be identified in the field are placed in labeled plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate a spacial coverage (percent distribution) estimate for each lake (KDHE, 2000).

Taste and Odor/Algae Bloom Program

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE district offices. While lakes used for public water supply are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis.

Figure 1. Locations of the 37 lakes surveyed during 2002.

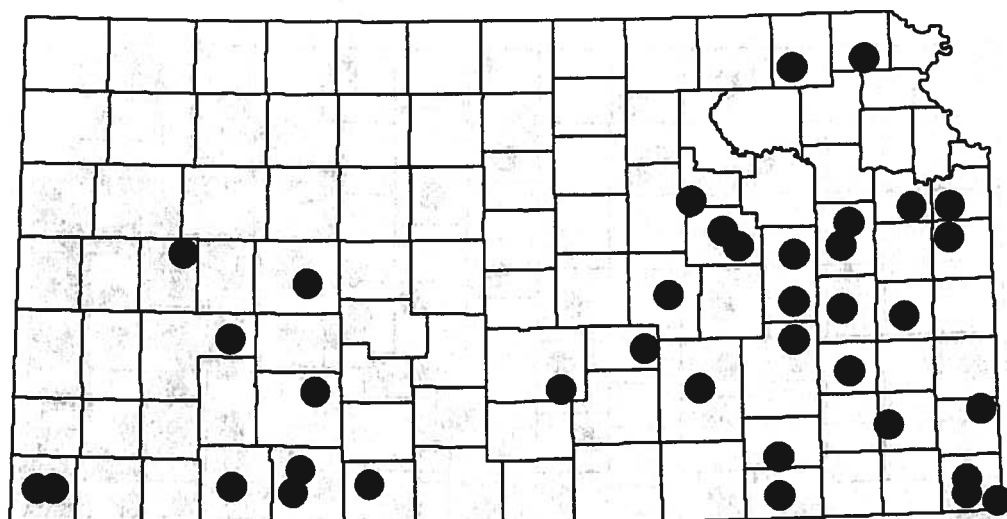
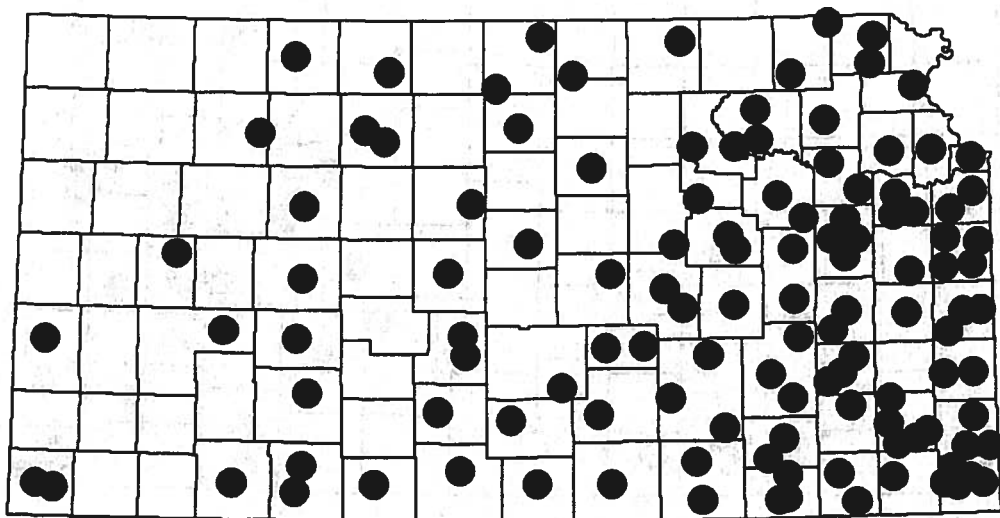


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program.



RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) provides a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 37 lakes surveyed during 2002, previous TSI mean scores for those lakes with past data, and an indication of the extent that lake productivity is dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll-a TSI scores are based on the planktonic algae community, production due to macrophyte beds is not reflected in these scores. The system used to assign lake trophic state, based on TSI scores, is presented below. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 50%, and visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production.

TSI score of 0-39 = oligo-mesotrophic (OM)

OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. Chlorophyll-a concentration averages no more than 2.5 ug/L.

TSI score of 40-49 = mesotrophic (M)

M = A lake with only a moderate planktonic algal community. Water clarity remains relatively high. Chlorophyll-a ranges from 2.51 to 7.2 ug/L.

TSI score of 50-63 = eutrophic (E)

E = A lake with a moderate-to-large algae community. Chlorophyll-a ranges from 7.21 to 30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic (SE)

Chlorophyll-a ranges 7.21 to 12.0 ug/L,

TSI = 55-59 = fully eutrophic (E)

Chlorophyll-a ranges 12.01 to 20.0 ug/L,

TSI = 60-63 = very eutrophic (VE)

Chlorophyll-a ranges 20.01 to 30.0 ug/L.

TSI score of ≥ 64 = hypereutrophic (H)

H = A lake with a very large phytoplankton community. Chlorophyll-a averages more than 30.0 ug/L. This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic

Chlorophyll-a ranges 30.01 to 55.99 ug/L,

TSI = ≥ 70 = upper hypereutrophic

Chlorophyll-a ranges ≥ 56 ug/L.

TSI score not relevant = argillotrophic (A)

A = In a number of Kansas lakes, high turbidity due to suspended clay particles restricts the development of a phytoplankton community. In such cases, nutrient availability remains high, but is not fully translated into algal productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal biomass, are called argillotrophic (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. These lakes may have chronic high turbidity, or may only experience sporadic (but frequent) episodes of dis-equilibria following storm events that create "over flows" of turbid runoff on the lake surface. Frequent wind resuspension of sediments, as well as benthic feeding fish communities (e.g., common carp), can create these conditions as well. Argillotrophic lakes also tend to have very small, or nonexistent, submersed macrophyte communities. Mean chlorophyll-a measures ≤ 7.2 ug/L as a general rule.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6 - (2.04 - 0.68 \log_e(C)) / \log_e(2)).$$

The composition of the algal community (structural feature) often gives a better ecological picture of a lake than relying solely on a trophic state classification (functional feature). Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 2002. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green algae, while those dominated by diatom communities may not be so enriched. Certain species of green, blue-green, diatom, or dinoflagellate algae may contribute to taste and odor problems in finished drinking water, when present in large numbers in lakes and streams.

Table 4 presents biovolume data for the 37 lakes surveyed in 2002. When compared to cell counts, such data are useful in determining which species or algae groups actually exert the strongest ecological influence on a lake.

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2002. Trophic class abbreviations used previously apply. An asterisk appearing after the lake name indicates that the lake was dominated, at least in part, by macrophyte production. In such a case, the trophic class is adjusted, and the adjusted trophic state class given in parentheses. Previous TSI scores are based only on algal chlorophyll TSI score.

Lake	2002 TSI/Class	Previous Trophic Class Period of Record Mean
Cedar Creek Lake	53.5 A	E
Centralia Lake	62.9 VE	H
Cheney Lake	58.0 E	A
Cimarron Lake	48.0 M	E
Clark Co. SFL	53.8 SE	SE
Concannon SFL	67.2 H	H
Council Grove City Lake	50.5 SE	M
Council Grove Lake	48.5 A	A
Douglas Co. SFL	62.2 VE	VE
El Dorado Lake	47.0 M	A
Empire Lake	34.9 A	SE/A
Ford Co. Lake	83.9 H	H
Gardner City Lake	59.4 E	VE
Geary Co. SFL	63.6 VE	VE
Goodman SFL	59.5 E	E
Harvey Co. East Lake	71.5 H	H
Hillsdale Lake ^s	53.3 SE	E
Hillsdale Lake Sta. 1 (Main Body)	54.0 SE	SE
Hillsdale Lake Sta. 2 (Big Bull Creek Arm)	53.7 SE	E
Hillsdale Lake Sta. 3 (Little Bull Creek Arm)	52.1 SE	E
John Redmond Lake	67.4 H	A
Lake Coldwater	61.4 VE	VE
Lake Crawford	62.8 VE	E
Lake Meade SFL	65.6 H	H

Lake	2002 TSI/Class	Previous Trophic Class Period of Record Mean
Lake Scott SFL*	83.7 H (H)	H
Lyon Co. SFL	51.3 SE	SE
Madison City Lake	44.8 M	SE
Marion Lake	66.3 H	E
Melvern Lake	52.6 SE	SE
Mined Land Lake 22	36.3 OM	M
Mined Land Lake 23	37.8 OM	M
Mission Lake	45.4 A	E
Moline City Lake #2*	37.9 OM (M)	M
Olpe City Lake	59.2 E	E
Point of Rocks Lake	61.8 VE	SE
Pomona Lake	55.5 E	A
Sedan North Lake	54.3 SE	SE
St. Jacob's Well	63.6 VE	H
Thayer New City Lake	48.9 M	M
Yates Center Lake	50.1 SE	SE

\$ = Hillsdale Lake's whole lake TSI is the mean of three individual stations within the lake.

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 37 lakes surveyed during 2002. Five lakes (13%) displayed increases in trophic state, compared to their historic mean condition, while eight lakes (22%) displayed improved trophic states. Stable conditions were noted in 24 lakes (65%). This is a larger percentage of lakes showing improved trophic state, compared to historic condition, than observed in recent years.

In general, lakes strongly influenced by nutrient inputs improved in water quality this year and last year, while those noted as light limited in the past generally seemed to have higher trophic state conditions and less turbidity. The drought conditions of the last couple years, and the reductions in runoff and the nutrients carried in runoff, would seem to have exerted some impact on water quality. Lakes having strong internal components creating high turbidity and light limitation (i.e., sizeable common carp populations or wind mixing) did not improve to any significant degree.

Table 3. Algal communities observed in the 37 lakes surveyed during 2002. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate groups of algae.

Lake	Cell Count (cells/mL)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Cedar Creek Lake	1,292	41	0	8	51
Centralia Lake	80,546	1	99	<1	<1
Cheney Lake	27,531	1	97	2	<1
Cimarron Lake	1,197	66	0	0	34
Clark Co. SFL	9,545	18	73	8	<2
Concannon SFL	225,225	3	97	<1	<1
Council Grove City Lake	13,734	17	76	6	2
Council Grove Lake	5,072	0	85	15	0
Douglas Co. SFL	124,992	0	99	1	0
El Dorado Lake	1,575	15	41	44	0
Empire Lake	756	54	0	33	13
Ford Co. Lake	1,016,285	<1	100	0	<1
Gardner City Lake	8,505	15	75	7	3
Geary Co. SFL	58,181	<1	96	2	2
Goodman SFL	10,773	54	7	16	23
Harvey Co. East Lake	28,508	46	17	33	4
Hillsdale Lake (mean)	6,920	21	45	31	3
Hillsdale Lake Sta. 1	7,623	16	56	24	4
Hillsdale Lake Sta. 2	6,048	17	33	47	3
Hillsdale Lake Sta. 3	7,088	30	46	21	2
John Redmond Lake	60,921	58	27	11	5
Lake Coldwater	5,607	15	11	17	57
Lake Crawford	7,025	62	8	3	27
Lake Meade SFL	20,979	52	46	2	<1
Lake Scott SFL	1,444,275	0	100	0	0

Lake	Cell Count (cells/mL)	Percent Composition			
		Greens	Blue-Greens	Diatoms	Other
Lyon Co. SFL	3,654	68	20	8	4
Madison City Lake	4,190	<2	79	17	3
Marion Lake	47,786	3	83	12	2
Melvern Lake	7,497	2	84	12	2
Mined Land Lake 22	1,134	43	54	3	0
Mined Land Lake 23	1,323	42	46	10	2
Mission Lake	567	6	0	65	29
Moline City Lake #2	788	100	0	0	0
Olpe City Lake	74,592	<1	97	2	<1
Point of Rocks Lake	16,569	81	7	3	9
Pomona Lake	8,442	2	62	34	2
Sedan North Lake	4,599	39	41	7	13
St. Jacob's Well	1,008	16	0	3	81
Thayer New City Lake	1,985	89	0	3	8
Yates Center Lake	2,741	54	36	0	9

As shown in Table 6, of the 26 lakes receiving macrophyte surveys (22 full surveys and 4 limited observational surveys) 17 (65% of those surveyed, 46% of all lakes in 2002) had detectable amounts of plant material. In these lakes, the most common plant species were pondweeds (Potamogeton spp.), water naiad (Najas guadalupensis), coontail (Ceratophyllum demersum), parrot feather (Myriophyllum spicatum), and various species of stonewort algae (Chara spp.). Myriophyllum spicatum, frequently noted as a nuisance organism in the literature, is becoming more common in Kansas, particularly in the western third of the state.

A comparison of macrophyte community relationships to reference water quality conditions indicated that communities with abundant Chara spp. are generally associated with better water quality conditions (low nutrient levels, high water clarity, few metal or pesticide exceedences, low algal biomass) than those without these plants. This is consistent with observations in the literature, in that stonewort algae seems to thrive in waters of better chemical quality, and may actually promote improved water quality conditions (Meijer, 2001; Scheffer, 1998; van den Berg, 2001).

Table 4. Algal biovolumes calculated for the lakes surveyed during 2002. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae. Biovolume units are calculated in mm^3/L , and expressed as parts-per-million (ppm).

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Cedar Creek Lake	6.915	4	0	3	93
Centralia Lake	39.633	<1	80	<1	19
Cheney Lake	13.323	7	61	32	<1
Cimarron Lake	3.950	16	0	0	84
Clark Co. SFL	14.384	18	54	22	6
Concannon SFL	44.512	3	91	4	3
Council Grove City Lake	13.649	11	63	13	13
Council Grove Lake	6.891	0	51	49	0
Douglas Co. SFL	27.513	0	92	8	0
El Dorado Lake	4.098	9	6	85	0
Empire Lake	2.637	11	0	77	12
Ford Co. Lake	298.871	<1	>99	0	<1
Gardner City Lake	5.113	38	24	26	11
Geary Co. SFL	31.008	<1	49	18	33
Goodman SFL	18.556	30	1	22	47
Harvey Co. East Lake	27.685	16	4	64	16
Hillsdale Lake (mean)	8.419	11	15	65	9
Hillsdale Lake Sta. 1	8.060	12	21	52	15
Hillsdale Lake Sta. 2	8.927	6	16	73	4
Hillsdale Lake Sta. 3	8.269	16	8	69	7
John Redmond Lake	36.766	37	11	16	35
Lake Coldwater	11.812	6	<1	2	92
Lake Crawford	8.970	19	1	4	76
Lake Meade SFL	25.372	86	7	2	4
Lake Scott SFL	282.082	0	100	0	0

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Lyon Co. SFL	2.381	55	8	21	15
Madison City Lake	1.723	10	48	25	17
Marion Lake	33.020	4	35	56	4
Melvorn Lake	10.262	<1	68	25	7
Mined Land Lake 22	0.942	56	38	6	0
Mined Land Lake 23	1.329	29	26	39	6
Mission Lake	2.467	20	0	45	35
Moline City Lake #2	0.523	100	0	0	0
Olpe City Lake	35.640	1	68	28	3
Point of Rocks Lake	38.655	45	<1	14	41
Pomona Lake	12.434	<1	10	87	3
Sedan North Lake	4.738	23	8	7	62
St. Jacob's Well	13.382	2	0	2	96
Thayer New City Lake	5.445	90	0	1	9
Yates Center Lake	3.728	25	6	0	69

Lake Stratification

Table 7 presents data related to thermal stratification in the 37 lakes surveyed in 2002, as well as calculated euphotic-to-mixed depth ratio.

Stratification is a natural process that may occur in any standing (lentic) body of water, whether that body is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (solar energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (the hypolimnion) remains near the bottom of the lake while the upper layer (the epilimnion) develops a higher ambient temperature. The middle layer (the metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion.

Table 5. Trends over time, based on a comparison to mean historic condition, for lake trophic state classification within each major river basin in Kansas. Only those basins visited during 2002 are included.

Basin	Number of Lakes		
	Stable	Improving	Degrading
Cimarron	3	2	1
Kansas/Lower Republican	2	2	0
Lower Arkansas	1	0	0
Marais des Cygnes	4	1	1
Neosho	5	0	3
Smoky Hill/Saline	2	0	0
Upper Arkansas	3	0	0
Verdigris	3	2	0
Walnut	1	1	0
Total	24	8	5

Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to become depleted of oxygen and unavailable as habitat for fish and other forms of aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. Typically occurring in the fall, this phenomenon is called "lake turnover."

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in finished drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich hypolimnetic water with epilimnetic water lower in nutrients and richer in dissolved oxygen. Lake turnover can result in explosive algal growth, lowering of overall lake oxygen levels, and sudden fishkills. It also often imparts objectionable odors to the lake water and tastes and odors to finished drinking water produced from the lake. Thus, the stratification process is an important consideration in lake management.

Table 6. Macrophyte community structure in the 26 lakes surveyed for macrophytes during 2002. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. The percent areal cover is the abundance estimate for each documented species (Note: due to overlap in cover, the percentages under community composition may not equal the total cover).

Lake	% Total Cover	% Species Cover and Community Composition	
Centralia Lake (limited survey)	>50%	abundant abundant	<i>Potamogeton pectinatus</i> <i>Najas guadalupensis</i>
Cimarron Lake	50%	50%	<i>Chara zeylanica</i>
Clark Co. SFL (limited survey)	~30%	present present present	<i>Ceratophyllum demersum</i> <i>Myriophyllum spicatum</i> <i>Potamogeton crispus</i>
Concannon SFL	<10%	no species observed	
Douglas Co. SFL	<5%	no species observed	
Ford Co. Lake	<10%	no species observed	
Gardner City Lake	<7%	present present	<i>Ceratophyllum demersum</i> <i>Najas guadalupensis</i>
Geary Co. SFL	20%	20% 20%	<i>Ceratophyllum demersum</i> <i>Potamogeton pectinatus</i>
Goodman SFL	<10%	no species observed	
Harvey Co. East Lake	<5%	no species observed	
Lake Coldwater	<5%	no species observed	
Lake Crawford	5%	5%	<i>Ceratophyllum demersum</i>
Lake Meade SFL	7%	7% 7%	<i>Chara zeylanica</i> <i>Najas guadalupensis</i>
Lake Scott SFL	85%	85%	<i>Myriophyllum spicatum</i>
Lyon Co. SFL	100%	100% 100% 100%	<i>Najas guadalupensis</i> <i>Potamogeton nodosus</i> <i>Potamogeton pectinatus</i>
Madison City Lake	<7%	no species observed	
Mined Land Lake 22 (limited survey)	>75%	abundant abundant	<i>Najas guadalupensis</i> <i>Potamogeton spp.</i>
Mined Land Lake 23 (limited survey)	>75%	abundant abundant	<i>Najas guadalupensis</i> <i>Potamogeton spp.</i>

Lake	% Total Cover	% Species Cover and Community Composition
Mission Lake	<5%	no species observed
Moline City Lake #2	80%	80% <i>Najas guadalupensis</i> 80% <i>Potamogeton pusillus</i> 60% <i>Chara zeylanica</i>
Olpe City Lake	<10%	no species observed
Point of Rocks Lake	100%	100% <i>Chara zeylanica</i>
Sedan North Lake	30%	30% <i>Nelumbo sp.</i>
St. Jacob's Well	60%	60% <i>Chara zeylanica</i> 15% <i>Utricularia vulgaris</i>
Thayer New City Lake	60%	60% <i>Najas guadalupensis</i> 40% <i>Potamogeton illinoensis</i>
Yates Center Lake	60%	45% <i>Najas guadalupensis</i> 40% <i>Potamogeton illinoensis</i> 30% <i>Potamogeton nodosus</i> 20% <i>Potamogeton amplifolius</i> 10% <i>Chara zeylanica</i>

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. The proportion of each depends on the strength and duration of stratification, existing sediment quality, and inflow of materials from the watershed.

Sediment re-release of materials, and water quality impact at turnover, would be most pronounced in a deep, moderate-to-small sized lake, with abundant protection from the wind, shallow thermocline, and a history of high pollutant loads from the watershed. For the majority of our larger lakes in Kansas, built on major rivers with dependable flow, stratification tends to be intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be small in proportion to total lake volume. These conditions tend to lessen the importance of sediment re-release of pollutants in the largest Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Table 7. Lake stratification status for the 37 lakes surveyed during 2002. The term "n.a." indicates that boat access, wind conditions, shallowness, or equipment problems prevented taking profile data or made its acquisition superfluous.

Lake	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio
Cedar Creek Lake	06-11-2002	0.85	0.64	6.5	10.5	0.53
Centralia Lake	06-10-2002	0.00	0.12	none	8.5	0.92
Cheney Lake	08-05-2002	0.08	0.48	none	12.0	0.62
Cimarron Lake	08-19-2002	0.00	0.00	none	2.0	5.69
Clark Co. SFL	07-09-2002	0.30	0.67	none	11.0	0.96
Concannon SFL	07-23-2002	0.00	0.00	none	1.5	6.70
Council Grove City Lake	07-16-2002	0.95	0.68	3.5-6.0	12.0	1.01
Council Grove Lake	08-15-2002	0.00	0.04	none	9.0	0.79
Douglas Co. SFL	06-17-2002	0.78	1.04	4.5	9.5	0.82
El Dorado Lake	08-06-2002	0.56	0.46	7.0-9.0	18.0	0.65
Empire Lake	06-03-2002	0.00	0.00	none	2.5	4.47
Ford Co. Lake ^s	07-08-2002	0.80	>0.00	none	2.5	1.00
Gardner City Lake	06-17-2002	0.96	0.83	4.5-5.5	12.0	0.82
Geary Co. SFL	07-01-2002	1.00	0.71	5.0-6.0	11.0	0.73
Goodman SFL	07-23-2002	0.00	0.00	none	2.0	2.35
Harvey Co. East Lake	07-16-2002	0.13	1.25	none	5.0	0.83
Hillsdale Lake Station 1	07-30-2002	0.81	0.75	7.0-8.0	13.0	0.76

Lake	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio
Hillsdale Lake Station 2	07-30-2002	0.63	0.85	7.0-8.0	8.5	1.16
Hillsdale Lake Station 3	07-30-2002	0.64	1.04	6.0-7.0	7.0	1.34
John Redmond Lake	08-14-2002	2.00	1.55	0.0-0.5	2.0	2.99
Lake Coldwater	07-09-2002	0.80	1.18	none	5.5	1.13
Lake Crawford	06-25-2002	0.24	0.59	none	14.5	0.69
Lake Meade SFL	07-09-2002	0.33	0.30	none	3.0	1.98
Lake Scott SFL	07-22-2002	0.25	1.25	none	4.0	0.47
Lyon Co. SFL	07-29-2002	n.a.	n.a.	n.a.	3.0	6.22
Madison City Lake	07-15-2002	1.69	0.88	3.0-4.5	10.0	1.20
Marion Lake	08-05-2002	0.06	0.34	none	8.5	0.64
Melvorn Lake	08-14-2002	0.39	0.31	11.0-13.0	19.0	0.66
Mined Land Lake 22	08-22-2002	1.71	1.31	4.0-5.5	7.0	1.34
Mined Land Lake 23	08-22-2002	0.40	0.90	none	5.0	1.77
Mission Lake	06-10-2002	1.50	1.55	2.5	4.0	1.33
Moline City Lake #2	06-24-2002	1.57	1.21	2.5-4.5	7.0	1.76
Olpe City Lake	07-15-2002	0.50	1.20	2.5	5.0	1.08
Point of Rocks Lake	08-19-2002	0.00	0.00	none	2.0	4.69
Pomona Lake	08-07-2002	0.32	0.55	4.0-6.0	15.0	0.67

Lake	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio
Sedan North Lake	06-24-2002	1.86	1.03	2.5-3.5	7.0	1.28
St. Jacob's Well	08-20-2002	n.a.	n.a.	n.a.	5.5	1.28
Thayer New City Lake	06-25-2002	2.38	1.15	2.0-4.0	9.0	1.25
Yates Center Lake	07-15-2002	1.41	0.96	4.0-6.0	8.5	1.25

\$ = Dissolved oxygen was higher than the scale limit (15.0 mg/L) in most of the water column during this survey. This precluded calculating a dissolved oxygen decline rate for Ford Co. Lake.

Presence or absence of stratification is determined by the depth profiles taken in each lake for temperature and dissolved oxygen concentration. Table 7 presents this data. Temperature decline rates (for the entire water column) greater than 1.0°C/m are considered evidence of stronger thermal stratification, although temperature changes may be less pronounced during the initiation phase of stratification. Lakes with strong thermal stratification will be more resistant to mixing of the entire water column pending the cooling of epilimnetic waters that accompanies fall.

The temperature decline rate, however, must also be considered in relation to the particular lake and the shape of the temperature-to-depth relationship. The sharper the discontinuity in the data plot, the stronger the level of thermal stratification. Gradual declines in temperature with depth, through the entire water column, and indistinct discontinuities in data plots are more indicative of weaker thermal stratification. The strength of the oxycline, based on water column decline rate and the shape of the data plot, is also used to estimate stratification in lakes. A strong oxycline might be seen by mid-summer in lakes with weak thermal stratification if the lakes are not prone to wind mixing, or in the case of dense macrophyte beds.

Euphotic depth, or the depth to which light sufficient for photosynthesis penetrates, can be calculated from relationships derived from Secchi depth and chlorophyll-a data (Scheffer, 1998). This report presents the ratio of calculated euphotic depth to calculated mixing depth, which is the depth to which wind circulation and stratification should reach typically. The metric supplies a means to interpret light and production relationships in a lake, provided other factors, such as depth and thermal stratification, are also considered simultaneously. For instance, a very high ratio may mean a lake is exceptionally clear, or may mean it is very shallow and well mixed. Examples of the former include Moline City Lake #2 and Mined Land Lake 23, while examples of the latter case include Empire Lake and Concannon SFL. A very low value likely means the lake is light limited due to inorganic turbidity (as in the case of Cedar Creek Lake) or self-shaded due to large algal biomass near the surface (as in the case of Lake Scott SFL).

Fecal Coliform Bacteria

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake. While many Kansas lakes have swimming beaches, many do not. However, presence or absence of a swimming beach does not determine whether or not a lake supports primary contact recreational use. Primary contact recreation is defined as, "recreation during which the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable" (KDHE, 2001), which includes swimming, water skiing, wind surfing, jet skiing, diving, boating, and other similar activities. The majority of Kansas lakes have some form of primary contact recreation taking place during the warmer half of the year. Sampling of swimming beaches is also often conducted by lake managers to document water quality where people are concentrated in a small area. These managers are in the best position to collect samples frequently enough to determine compliance with the regulations at these swimming beaches (KDHE, 2001).

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform bacterial counts should only occur in the open water of a lake if there has been 1) a recent pollution event, or 2) a chronic input of bacteria-laced pollution. A single set of bacterial samples collected from the open, deep water, environment is normally considered representative of whole-lake bacterial water quality at the time of the survey. This environment is also less prone to short lived fluctuations in bacterial counts, than are swimming beaches or other shoreline type areas.

Table 8 presents the bacterial data collected during the 2002 sampling season. Eight lakes, out of the 34 lakes surveyed for fecal coliform bacteria (Empire Lake and Mined Land Lakes 22 and 23 were not sampled), had fecal coliform bacterial counts greater than the analytical reporting limit. Only three lakes in 2002 had both duplicate samples greater than analytical reporting limit. However, no lake in 2002 exceeded existing criteria (KDHE, 2001).

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 34 lakes surveyed for fecal coliform bacteria during 2002. Note: These samples were collected during the week, not during weekends, when recreational activity would be at peak levels. All units are in "number of cfu/100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Cedar Creek Lake	open water	<10
Centralia Lake	open water	<10
Cheney Lake	open water	<10
Cimarron Lake	open water	45
Clark Co. SFL	open water	<10
Concannon SFL	open water	<10
Council Grove City Lake	open water	<10
Council Grove Lake	open water	<10
Douglas Co. SFL	open water	<10
El Dorado Lake	open water	<10
Ford Co. Lake	open water	<10
Gardner City Lake	open water	<15
Geary Co. SFL	open water	<10
Goodman SFL	open water	10
Harvey Co. East Lake	open water	<10

Lake	Site Location	Fecal Coliform Count
Hillsdale Lake	open water	<10
John Redmond Lake	open water	<10
Lake Coldwater	open water	<10
Lake Crawford	open water	<10
Lake Meade SFL	open water	<15
Lake Scott SFL	open water	<15
Lyon Co. SFL	off dam face	<15
Madison City Lake	swimming area	100
Marion Lake	open water	<10
Melvorn Lake	open water	<10
Mission Lake	open water	<10
Moline City Lake #2	open water	<10
Olpe City Lake	open water	<10
Point of Rocks Lake	open water	<10
Pomona Lake	open water	<10
Sedan North Lake	open water	<10
St. Jacob's Well	open water	<20
Thayer New City Lake	open water	<10
Yates Center Lake	open water	<10

Limiting Nutrients and Physical Parameters

The determination of which nutrient, or physical characteristic, “limits” phytoplankton production is of primary importance in lake management. If certain features can be identified, which exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

Common factors that limit algal production in lakes are the level of available nutrients (phosphorus and nitrogen, primarily), and the amount of light available in the water column for photosynthesis. Less common limiting factors in lakes, and other lentic waterbodies, include available levels of carbon, iron, and certain trace elements (such as molybdenum or vitamins), as well as grazing pressure, temperature, or hydrologic flushing rate.

Nutrient ratios are commonly considered in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical elements versus availability in the environment. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 10-12 indicate increasing phosphorus limitation. Conversely, TN/TP ratios of less than 7-10 indicate increasing importance of nitrogen. Ratios of 7-to-12 indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983; Horne and Goldman, 1994). It should also be kept in mind, when determining limiting factors, that highly turbid lakes typically have lower nutrient ratios, but may still have phosphorus limitation due to availability issues (Jones and Knowlton, 1993)

Table 9 presents limiting factor determinations for the lakes surveyed during 2002. It should be kept in mind that these determinations reflect the time of sampling, which is chosen to reflect average conditions during the summer growing season to the extent possible, but may be less applicable to other times of the year. There is, however, always the chance that conditions during one survey will differ from conditions during past surveys, despite efforts to sample during times representative of “normal” summer conditions. If such a situation is suspected, it will be noted in Table 9 or elsewhere in the report.

Table 9. Limiting factor determinations for the 37 lakes surveyed during 2002. NAT = non-algal turbidity, TN/TP = nitrogen-to-phosphorus ratio, Z_{mix} = depth of mixed layer, Chl-a = chlorophyll-a, and SD = Secchi depth. N = nitrogen, P = phosphorus, C = carbon, Fe = iron, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

Lake	TN/TP	NAT	Z_{mix} *NAT	Chl-a*SD	Chl-a/TP	Z_{mix} /SD	Shading	Factors
Cedar Creek Lake	6.0	3.076	10.861	3.09	0.064	11.771	8.95	L
Centralia Lake	14.1	0.315	0.937	27.27	0.491	2.945	4.99	P>N
Cheney Lake	6.2	0.889	3.988	12.63	0.143	5.827	8.11	N \geq (P=L)
Cimarron Lake	19.0	0.853	0.512	5.90	0.118	0.601	1.05	Unknown=P
Clark Co. SFL	17.3	0.503	1.824	13.85	0.213	2.790	4.92	P>N
Concannon SFL	32.5	1.041	0.298	20.02	0.190	0.596	1.17	Unknown \geq (P=N)
Council Grove City Lake	21.7	0.415	1.580	12.62	0.255	2.308	4.74	P>N
Council Grove Lake	4.0	1.458	5.192	3.84	0.032	5.744	5.95	L>N
Douglas Co. SFL	50.7	0.473	1.572	22.80	0.835	3.654	5.71	P
El Dorado Lake	12.0	0.613	3.571	7.17	0.178	4.351	9.12	(N>P)=L
Empire Lake	15.0	1.922	1.155	0.79	0.007	1.178	1.34	Hydrology
Ford Co. Lake	7.9	<0.010	<0.010	156.26	0.455	1.324	5.29	N
Gardner City Lake	21.4	0.367	1.396	22.55	0.421	3.200	5.87	P
Geary Co. SFL	18.3	0.352	1.275	26.92	0.579	3.900	6.52	P>N
Goodman SFL	16.1	4.287	2.576	3.99	0.136	2.861	2.54	Unknown
Harvey Co. East Lake	11.2	0.258	0.531	34.53	0.521	3.884	5.52	N \geq P
Hillsdale Lake (whole lake)	13.0	0.374	1.779	16.15	0.225	2.983	6.65	P=N

Lake	TN/TP	NAT	Z _{mix} *NAT	Chl-a*SD	Chl-a/TP	Z _{mix} /SD	Shading	Factors
Hillsdale Lake Station 1	13.5	0.391	1.858	16.38	0.217	3.148	6.79	P=N
Hillsdale Lake Station 2	13.1	0.342	1.097	17.41	0.264	1.941	4.01	P>N
Hillsdale Lake Station 3	12.4	0.392	1.105	14.58	0.200	1.739	3.43	P=N
John Redmond Lake	5.1	2.386	1.209	12.33	0.181	1.747	2.11	N>L
Lake Coldwater	24.3	0.868	1.942	16.04	0.581	3.243	4.06	P
Lake Crawford	12.7	<0.010	<0.010	40.43	0.443	2.898	7.28	P=N
Lake Meade SFL	15.3	0.484	0.568	25.88	0.322	1.610	2.52	P>N
Lake Scott SFL	4.9	<0.010	<0.010	65.50	0.370	5.705	10.02	(N>P)>C
Lyon Co. SFL	17.8	0.460	0.277	12.38	0.206	0.401	0.96	P>N
Madison City Lake	39.3	0.449	1.541	7.65	0.283	1.906	3.91	P
Marion Lake	7.1	0.609	2.061	24.42	0.293	5.290	7.27	N
Melvern Lake	20.8	0.249	1.496	19.47	0.315	2.915	9.21	P
Mined Land Lake 22	329.0	0.174	0.647	8.21	0.180	0.814	3.56	Fe>P
Mined Land Lake 23	169.3	0.156	0.437	10.08	0.105	0.584	2.59	Fe>P
Mission Lake	14.1	2.589	4.284	1.68	0.028	4.472	3.54	Unknown
Moline City Lake #2	91.0	0.242	0.654	7.14	0.210	0.796	2.60	Macrophytes=P
Olpe City Lake	15.1	1.713	3.525	8.49	0.231	4.474	4.27	(P=N)>L
Point of Rocks Lake	37.2	0.395	0.237	24.20	0.440	0.601	1.27	P
Pomona Lake	11.1	0.376	1.965	18.36	0.283	3.632	8.14	N>P

Lake	TN/TP	NAT	Z _{mix} *NAT	Chl-a*SD	Chl-a/TP	Z _{mix} /SD	Shading	Factors
Sedan North Lake	24.7	0.501	1.357	14.34	0.320	2.115	3.58	P
St. Jacob's Well	18.9	0.048	0.107	37.51	0.481	1.721	3.57	P>N
Thayer New City Lake	35.2	0.378	1.215	12.03	0.260	1.737	3.72	P
Yates Center Lake	22.6	0.420	1.301	12.12	0.292	1.866	3.70	P

Criteria Table

Expected Lake Condition	TN/TP	NAT	Z _{mix} *NAT	Chl-a*SD	Chl-a/TP	Z _{mix} /SD	Shading
Phosphorus Limiting	>12				>0.40		
Nitrogen Limiting	<7				<0.13		
Light/Flushing Limited		>1.0	>6	<6	<0.13	>6	>16
High Algae-to-Nutrient Response		<0.4	<3	>16	>0.40	<3	
Low Algae-to-Nutrient Response		>1.0	>6	<6	<0.13	>6	
High Inorganic Turbidity		>1.0	>6	<6		>6	>16
Low Inorganic Turbidity		<0.4	<3	>16		<3	<16
High Light Availability			<3	>16		<3	<16
Low Light Availability			>6	<6		>6	>16

As indicated in Table 9, phosphorus was the primary limiting factor identified for lakes surveyed in 2002. Sixteen of the 37 lakes (43%) were determined to be primarily limited by phosphorus. Seven lakes (19%) were determined to be primarily nitrogen limited. Two lakes were primarily light limited (5%). Another four lakes (11%) were co-limited by phosphorus and nitrogen or limited by combinations of nutrients and/or light availability. Two lakes (5%) were primarily limited by iron availability. One lake (3%) was determined to be limited by biological interactions with the macrophyte community, combined with phosphorus. One lake (3%) was determined to be primarily limited by hydrologic conditions. Finally, four lakes (11%) had factors operating which could not be clearly identified.

In addition to nutrient ratios, the following six metrics are considered to help determine the relative roles of light and nutrient limitation for lakes in Kansas (Walker, 1986; Scheffer, 1998).

1) Non-Algal Turbidity = $(1/SD) - (0.025 \text{ m}^2/\text{mg} \cdot \text{C})$,

where SD = Secchi depth in meters and C = chlorophyll-a in mg/m^3 .

Non-algal turbidity values $<0.4 \text{ m}^{-1}$ tend to indicate very low levels of suspended silt and/or clay, while values $>1.0 \text{ m}^{-1}$ indicate that inorganic particles are important in creating turbidity. Values between 0.4 and 1.0 m^{-1} describe a range where inorganic turbidity assumes greater influence on water clarity as the value increases, but would not assume a significant limiting role until values exceed 1.0 m^{-1} .

2) Light Availability in the Mixed Layer = $Z_{\text{mix}} \cdot \text{Non-Algal Turbidity}$,

where Z_{mix} = depth of the mixed layer, in meters, and non-algal turbidity.

Values <3 indicate abundant light, within the mixed layer of a lake, and a high potential algal response to nutrients. Values >6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Non-Algal Turbidity = $\text{Chl-a} \cdot \text{SD}$,

where Chl-a = chlorophyll-a in mg/m^3 and SD = Secchi depth in meters.

Values <6 indicate that inorganic turbidity dominates light extinction in the water column and there is a weak algal response to changes in nutrient levels. Values >16 indicate the opposite.

4) Algal Use of Phosphorus Supply = $\text{Chl-a}/\text{TP}$,

where Chl-a = chlorophyll-a in mg/m^3 and TP = total phosphorus in mg/m^3 .

Values <0.13 indicate a low algal response to phosphorus, indicating that nitrogen, light, or other factors may be important. Values above 0.4 indicate a strong algal response to changes in phosphorus level. The range between 0.13-to-0.4 suggests a variable but moderate response by algae to phosphorus.

5) Light Availability in the Mixed Layer for a Given Surface Light = Z_{mix}/SD ,

where Z_{mix} = depth of the mixed layer, in meters, and SD = Secchi depth in meters.

Values <3 indicate that light availability is high and potential algal response to changes in nutrient levels is high. Values >6 indicate the opposite.

6) Shading in Water Column due to Algae and Inorganic Turbidity = $Z_{\text{mean}} * E$,

where Z_{mean} = mean lake depth, in meters, and E = calculated light attenuation coefficient, in units of m^{-1} , derived from Secchi depth and chlorophyll-a data (Scheffer, 1998).

Values >16 indicate high levels of self-shading due to algae or inorganic turbidity in the water column. Values <16 indicate that self-shading of algae does not significantly impede productivity. The metric is most applicable to lakes with maximum depths less than 5 meters (Scheffer, 1998).

In addition to the preceding metrics, an approach put forth by Dr. Robert Carlson (1991) was used to test the limiting factor determinations made from the suite of metrics used in this, and previous, reports. The approach uses the Carlson trophic state indices for total phosphorus, chlorophyll-a, Secchi depth, and the newer index for total nitrogen. Index scores are calculated for each lake, then metrics are calculated for $\text{TSI}_{(\text{Secchi})} - \text{TSI}_{(\text{Chl-a})}$ and for $\text{TSI}_{(\text{TP or TN})} - \text{TSI}_{(\text{Chl-a})}$. The degree of deviation of each of these metrics from zero provides a measure of their potential limiting factors. In the case of the metric dealing with Secchi depth and chlorophyll, a positive difference indicates small particle turbidity is important, while a negative difference indicates that larger particles (zooplankton, algal colonies) exert more importance. In the case of the metric dealing with nutrients, a positive difference indicates the nutrient in question may not be the limiting factor, while a negative difference strengthens the assumption that the particular nutrient limits algal production and biomass. Differences of more than 5 units were used as the threshold for determining if the deviations were significantly different from zero. This approach generally produced the same determinations as those derived from the use of the suite of metrics. It clearly identified those lakes with extreme turbidity or those with algal colonies or large celled algal species.

In identifying the limiting factors for lakes, primary attention was given to the metrics calculated from 2002 data. However, past Secchi depth and chlorophyll-a data were also used in comparison to 2002 data. Additionally, mean and maximum lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidity may have little real impact from that turbidity if the entire water column rapidly circulates (Scheffer, 1998).

Surface Water Exceedences of State Water Quality Criteria

Most numeric and narrative water quality criteria referred to in this section are taken from the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA, 1972, 1976; KDHE, 2001) for ambient waters and finished drinking water. Copies of the Standards may be obtained from the Bureau of Water, KDHE, 1000 Southwest Jackson Ave., Suite 420, Topeka, Kansas 66612.

Tables 11, 12, and 13 present documented exceedences of surface water quality criteria and goals during the 2002 sampling season. These data were generated by comparison of a computer data retrieval, for the 2002 Lake and Wetland Monitoring Program ambient data, to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth of 3.0 meters, or less, were used to document standards violations, as a majority of those samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities, compared to overlying waters, do not generally pose a significant water quality problem for the lake as a whole.

Eutrophication and/or turbidity related criteria in the Kansas Surface Water Quality Standards are narrative rather than numeric. This is partially due to the fact that the trophic state of any individual lake reflects a number of site-specific and regional environmental characteristics, combined with pollutant inputs from its watershed. However, lake trophic state does exert a documented impact on various lake uses, as does inorganic turbidity. The system on the following page (Table 10) has been developed over the last ten years to define how lake trophic status influences the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). These trophic state/use support combinations are joined with the site-specific lake trophic state designations to determine expected use support levels at each lake. See the report appendix for an updated comparison of these trophic class based assessments, as well as turbidity based assessments, versus risk based values developed over the last five years.

With respect to the aquatic life support use, eutrophication, high pH, and low dissolved oxygen within the upper 3.0 meters comprised the primary water quality concerns during 2002 (Table 11). Twenty-three lakes exhibited trophic states high enough to impair long or short term aquatic life support. Eight lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column. Four lakes had pH levels high enough to impact aquatic life support. Sixteen lakes exhibited chronic turbidity sufficient to impact long term community structure and function.

Table 10. Lake use support determination based on lake trophic state (Also see the Appendix.).

Designated Use	A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life Support	X	Full	Full	Full	Partial	Partial	Non	Non
Drinking Water Supply	X	Full	Full	Partial	Partial	Non	Non	Non
Primary Contact Recreation	X	Full	Full	Partial	Partial	Non	Non	Non
Secondary Contact Recreation	X	Full	Full	Full	Partial	Partial	Non	Non
Livestock Water Supply	X	Full	Full	Full	Partial	Partial	Non	Non
Irrigation	X	Full	Full	Full	Partial	Partial	Non	Non
Groundwater Recharge								
Food Procurement								
Trophic state is not generally applicable to this use.								
Trophic state is applicable to this use, but not directly.								

BG = blue-green algae dominate the community (50%+ as cell count and/or 33%+ as biovolume)

X = use support assessment based on nutrient load and water clarity, not algal biomass

A = argillotrophic (high turbidity lake)

M = mesotrophic (includes OM, oligo-mesotrophic, class), TSI = zero-to-49.9

SE = slightly eutrophic, TSI = 50-to-54.9

E = eutrophic (fully eutrophic), TSI = 55-to-59.9

VE = very eutrophic, TSI = 60-to-63.9

H = hypereutrophic, TSI ≥ 64

TSI = 64 = chlorophyll-a of 30 ug/L

TSI = 70 = chlorophyll-a of 56 ug/L

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems are generally due to advanced trophic state, which causes rapid oxygen depletion below the thermocline, but are also observed in lakes that do not exhibit excessive trophic state conditions. In these cases, the low dissolved oxygen levels likely result from shallow stratification conditions. Lakes with elevated pH are also reflective of high trophic state and algal or macrophytic production.

During 2002, the third consecutive year of exceptionally dry and hot summer conditions, many lakes showed clearer water columns than observed in past times. El Dorado and Pomona Lakes were notable examples of this. The extended dry conditions, which have led to greatly reduced runoff and inflows at many lakes and subsequent drops in water level at some, have also resulted in reductions in the magnitude and frequency of water quality standards exceedences related to pesticides and heavy metals. However, in some cases, lower water levels have allowed resuspension of sediments, bringing silt and associated pollutants into water columns. For lakes typically limited by nutrient inputs, the net result has been to improve overall water quality except for those lakes with water levels lowered to the degree that resuspension exerts impacts. For lakes typically light limited, the effect has often been to trade turbidity for algal biomass, some of which have begun to exhibit impacts due to trophic state increases. However, in lakes where wind resuspension or bottom feeding fish communities create turbid conditions, the effects of reduced silt/clay inputs are not discernable.

There were 33 exceedences of water supply criteria and/or guidelines during 2002 (Table 12). The majority were for eutrophication related conditions (70%). Of these 33 exceedences, only 10 (30%) occurred in lakes that currently serve as public water supplies. Irrigation use criteria were exceeded in 14 lakes, none of which currently are designated for irrigation supply pending a use attainability analysis. Livestock water criteria were exceeded in 17 lakes, two of which are currently a livestock water source. The remaining 15 lakes have not yet had a use attainability assessment for livestock water use. Human health criteria for arsenic were exceeded in one lake.

Table 13 lists 24 lakes with trophic state/turbidity conditions high enough to impair contact recreational uses. Nineteen of the lakes surveyed had high enough trophic state or turbidity to impair secondary contact recreation during 2002.

In all, there were 224 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 2002. Of these, 38% related to aquatic life support, 34% related to consumptive uses, and 28% related to recreational uses. A total of 73% of these exceedences occurred in lakes designated for the particular uses, while 27% occurred in lakes where uses have not yet been verified through use attainability analyses. Eutrophication, turbidity, high pH, or low dissolved oxygen account for 84% of total water quality impacts in 2002. Only 6% of water quality impacts were linked to heavy metals and metalloids, some of which may relate to copper sulphate treatments in water supply lakes. There were no pesticide related water quality exceedences in 2002, although detections of acetochlor (a replacement herbicide for atrazine) seem to be increasing in both frequency and magnitude. This may represent a future water quality concern.

Table 11. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 2002. DO = dissolved oxygen, EN = eutrophication or high nutrient load, and TN = high turbidity and nutrient load. Only those lakes with some documented water quality problem are included in Tables 11, 12, and 13.

Lake	Chronic ALS							Acute ALS			
	EN*	TN*	pH*	DO*	Cu	Pb	Se	EN*	pH*	DO*	Cu
Cedar Creek Lake	X	X				X		X			
Centralia Lake	X										
Cheney Lake	X	X									
Cimarron Lake		X									
Concannon SFL	X	X						X			
Council Grove Lake	X	X									
Douglas Co. SFL	X					X		X			
Empire Lake	X	X				X					
Ford Co. Lake	X	X	X	X				X	X	X	
Gardner City Lake	X				X						X
Geary Co. SFL	X							X			
Goodman SFL	X	X					X				
Harvey Co. East Lake	X	X						X			
John Redmond Lake	X	X						X			
Lake Coldwater	X	X		X				X			
Lake Crawford	X							X			

	Chronic ALS							Acute ALS			
	EN*	TN*	pH*	DO*	Cu	Pb	Se	EN*	pH*	DO*	Cu
Lake Meade SFL	X	X						X			
Lake Scott SFL	X	X	X	X				X	X	X	
Madison City Lake				X							
Marion Lake	X	X						X			
Mined Land Lake 23				X						X	
Mission Lake	X	X		X						X	
Moline City Lake #2			X		X				X		
Olpe City Lake	X	X									
Point of Rocks Lake	X		X					X	X		
Pomona Lake	X										
Sedan North Lake				X						X	
St. Jacob's Well	X							X			
Thayer New City Lake				X	X					X	X

* = Although there are no specific chronic versus acute criteria for these parameters, the magnitude of the excursions are used to determine whether the impact is immediate or of a more long term importance.

Table 12. Exceedence of human use criteria and/or EPA guidelines within the surface waters of the lakes surveyed during 2002. EN = high trophic state or nutrient loads. Only lakes with documented exceedences are included within the table. An "X" indicates that the exceedence occurred for a presently designated use. An "(X)" indicates that the exceedence occurred where the indicated use has not yet been verified by use attainability analyses.

Lake	Water Supply					Irrigation			Livestock Water			Human Health (i.e., Food Procurement)	
	EN	Cl	SO ₄	F	NO ₃	EN	B	F	EN	SO ₄	F	As	
Cedar Creek Lake	X												
Centralia Lake	X					(X)			(X)				
Cheney Lake	X												
Concannon SFL	(X)	(X)	(X)			(X)	(X)	(X)	(X)	(X)		X	
Council Grove Lake	X												
Douglas Co. SFL	(X)					(X)			(X)				
Empire Lake	(X)												
Ford Co. Lake	(X)					(X)			(X)				
Gardner City Lake	X												
Geary Co. SFL	(X)					(X)			(X)				
Goodman SFL	(X)		(X)							(X)			
Harvey Co. East Lake	(X)					(X)			(X)				
John Redmond Lake	X					(X)			(X)				
Lake Coldwater	X					(X)			(X)				
Lake Crawford	(X)					(X)			(X)				

Lake	Water Supply					Irrigation			Livestock Water			Human Health (i.e., Food Procurement)
	EN	Cl	SO ₄	F	NO ₃	EN	B	F	EN	SO ₄	F	
Lake Meade SFL	(X)					(X)		(X)	(X)			
Lake Scott SFL	(X)			(X)		(X)		(X)	(X)		(X)	
Marion Lake	X					(X)			(X)			
Mined Land Lake 22			(X)							(X)		
Mined Land Lake 23			(X)		(X)					(X)		
Mission Lake	X											
Olpe City Lake	(X)											
Point of Rocks Lake	(X)		(X)	(X)		(X)	(X)	(X)	X	X	X	
Pomona Lake	X											
St. Jacob's Well	(X)			(X)		(X)		(X)	X		X	

Table 13. Exceedences of numeric and narrative recreational guidelines for lakes surveyed during 2002. Primary contact recreation refers to recreation where ingestion of lake water is likely. Secondary contact recreation involves a low likelihood of accidental ingestion of lake water. EN = high trophic state or nutrient loads and TN = high turbidity and nutrient loads. An "X" indicates that a use attainability study has been completed and/or the use was previously designated for that lake. Only lakes with impairments are listed.

Lake	Primary Contact Recreation		Secondary Contact Recreation	
	EN	TN	EN	TN
Cedar Creek Lake	X	X		X
Centralia Lake	X		X	
Cheney Lake	X	X		
Cimarron Lake		X		
Concannon SFL	X	X	X	X
Council Grove Lake	X	X		
Douglas Co. SFL	X		X	
Empire Lake	X	X		X
Ford Co. Lake	X	X	X	
Gardner City Lake	X			
Geary Co. SFL	X		X	
Goodman SFL	X	X		X
Harvey Co. East Lake	X	X	X	X
John Redmond Lake	X	X	X	X
Lake Coldwater	X	X	X	
Lake Crawford	X		X	
Lake Meade SFL	X	X	X	
Lake Scott SFL	X	X	X	X
Marion Lake	X	X	X	
Mission Lake	X	X		X
Olpe City Lake	X	X		X
Point of Rocks Lake	X		X	

Lake	Primary Contact Recreation		Secondary Contact Recreation	
	EN	TN	EN	TN
Pomona Lake	X			
St. Jacobs Well	X		X	

Pesticides in Kansas Lakes, 2002

Detectable levels of at least one pesticide were documented in the main body of 21 lakes sampled in 2002 (62% of lakes surveyed for pesticides). Table 14 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Four different pesticides, and one pesticide degradation byproduct, were noted in 2002. Of these five compounds, atrazine and alachlor currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 2001).

Atrazine continues to be the pesticide detected most often in Kansas lakes (KDHE, 1991). Atrazine, and the atrazine degradation byproduct deethylatrazine, accounted for 64% of the total number of pesticide detections, and atrazine and/or deethylatrazine were detected in all 21 lakes. In addition to atrazine, eight lakes had detectable levels of metolachlor (Dual), five had detectable levels of alachlor (Lasso), and three had detectable levels of acetochlor (Harness or Surpass). Nine lakes had detectable quantities of the atrazine degradation byproduct deethylatrazine.

In almost all cases, the presence of these pesticides was directly attributable to agricultural activity. No lake in 2002 exceeded applicable numeric criteria, but several represent concerns based on numbers and amounts of pesticides present in the water column. Based on the number of different pesticides detected, Cedar Creek Lake, Centralia Lake, Harvey Co. East Lake, Hillsdale Lake, Mission Lake, and Pomona Lake are of most concern. In terms of total maximum concentrations, Cedar Creek Lake, Hillsdale Lake, and Mission Lake (all water supply lakes) would be of most concern. In the case of Mission Lake, the concern is based on the herbicide acetochlor, which was introduced in the mid 1990s as a substitute for atrazine use. It is interesting to note that, although atrazine did not occur in conjunction with acetochlor in Mission Lake, a considerable amount of atrazine byproduct was detected. This suggests atrazine remains a concern in this watershed. A general increase in the frequency and magnitude of acetochlor detections in lakes in northeast Kansas has been noted for the past few years.

Another interesting feature of pesticide sampling in 2002 seems to be that the reduced runoff and rainfall of the last couple years has not reduced the number of detected pesticides, or their frequency of detection, to any significant degree. It is possible that most pesticide loads are occurring in association with runoff from intense storm events, which could occur even during drought years.

Alternatively, a large portion of pesticide loadings might be associated with baseflow and subsurface drainage. A third alternative is that atmospheric drift, deposition, and dry-fall may constitute a significant component of pesticide loadings for some of these lakes.

Table 14. Pesticides levels documented during 2002 in Kansas lakes. All values listed are in ug/L. Analytical quantification limits are as follows: atrazine = 0.3 ug/L, deethylatrazine = 0.3 ug/L, metolachlor = 0.25 ug/L, alachlor = 0.1 ug/L, and acetochlor = 0.1 ug/L. Only those lakes with detectable levels of pesticides are reported.

Lake	Pesticide				
	Atrazine	Deethylatrazine	Metolachlor	Alachlor	Acetochlor
Cedar Creek Lake	2.60	0.37	0.60	0.11	0.16
Centralia Lake	1.80	0.51	1.00	0.56	
Cheney Lake	0.42				
Clark Co. SFL	0.96				
Concannon SFL	1.60	0.67			
Council Grove City Lake	0.32				
Council Grove Lake	0.87				
El Dorado Lake	0.37				
Ford Co. Lake		1.10	0.46		
Gardner City Lake	1.60			0.23	
Goodman SFL	0.43				
Harvey Co. East Lake	0.83	0.55	0.71	0.13	
Hillsdale Lake	2.30	0.44			0.13
John Redmond	1.60		0.39		
Lake Coldwater	1.10				
Lake Scott SFL	0.53				
Lyon Co. SFL	1.40	0.35			
Marion Lake	1.30		0.35		

Lake	Pesticide				
	Atrazine	Deethylatrazine	Metolachlor	Alachlor	Acetochlor
Melvern Lake	1.70				
Mission Lake		1.60	0.29		2.10
Pomona Lake	1.40	0.35	0.30	0.30	

Discussion of Nonpoint Sources of Pollution for Selected Lakes

Nineteen lakes were chosen for further discussion, based on the number and type of observed surface water quality impacts. A waterbody was chosen if 1) three, or more, parameters exceeded their respective chronic aquatic life support criteria/guidelines, 2) more than two parameters exceeded applicable acute aquatic life support criteria/guidelines, or 3) more than one parameter exceeded irrigation, water supply, livestock watering, or recreational criteria. Possible causes and sources of these documented water quality problems are considered below.

Cedar Creek Lake The primary water quality problems associated with this moderate sized water supply lake include nutrient enrichment and inorganic turbidity. With a watershed nearly two-thirds cultivated ground, and a watershed/lake ratio >100, the primary source of impairment is clearly agriculture, exacerbated by the large contributing area.

Cheney Lake The primary water quality problems associated with this large water supply lake include nutrient enrichment and inorganic turbidity. With a watershed more than 50% cultivated land, and a watershed/lake ratio of 62, agriculture clearly is the primary source of pollutants. However, in the case of Cheney Lake, it is believed wind resuspension of sediments contributes significantly to water quality problems.

Concannon SFL Primary water quality problems include nutrient enrichment and inorganic turbidity at this small recreational lake, but secondary problems also include certain inorganic parameters and metals. With a watershed >75% cultivated land, and a watershed/lake ratio >1,500, agriculture is the primary source of pollutants. Loss of spring flows and inflow volume in recent years has also made this lake prone to evaporative concentration of certain pollutants. The resultant lower water levels also make resuspension of pollutants retained within the sediments more probable.

Council Grove Lake Primary water quality problems at this moderately large lake are related to nutrient enrichment and inorganic turbidity. With a watershed possessing a large percentage of cultivated land, and a watershed/lake ratio of 59, agriculture is identified as the primary source of pollutants.

Empire Lake Primary water quality problems at Empire Lake revolve around nutrient enrichment and inorganic turbidity. That this lake is a shallow impoundment on the third largest river in Kansas (based on discharge volume), with a truly enormous watershed drainage into it, most water quality problems can be linked to the physical and hydrological setting with both agriculture and upstream point sources providing pollutants. Although heavy metals were not a concern in the water column per se, this river basin has many such water and sediment contamination concerns, owing to past mining practices.

Ford Co. Lake Primary water quality problems at this small recreational lake revolve around nutrient enrichment and the secondary impacts of pH and diel dissolved oxygen cycles. The watershed of this lake is roughly 75% cultivated land, with a watershed/lake ratio of >350. While agriculture is the primary source of pollutants, it is exacerbated by the large amount of drainage, and recent hydrologic impacts from drought.

Goodman SFL Primary water quality problems revolve around nutrient enrichment and evaporative concentration of some inorganic constituents. The watershed of this small recreational lake is about 40% cultivated land, with a watershed/lake ratio of >170. While agriculture is the primary source for pollutants, recent water quality problems at Goodman SFL come from hydrologic losses and the loss of the lake's former, robust macrophyte community. These have allowed the accumulated nutrients in the lake to fuel increases in trophic state to the detriment of many uses.

Harvey Co. East Lake Water quality problems at this moderate sized recreational lake result from nutrient enrichment and inorganic turbidity. The watershed of this lake is about 60% cultivated land, with numerous small animal confinement areas, and a watershed/lake ratio of 42. Agriculture is the primary source of pollutants to this lake.

John Redmond Lake This large Federal lake has nutrient enrichment and inorganic turbidity as its primary water quality problems. The watershed has a majority of the land in cultivation, at least one major municipal point source (Emporia), and a watershed/lake ratio of >190. Under normal yearly conditions, this lake has a short hydrologic turnover time, which keeps nutrients from realizing their potentials. Under these conditions, the primary water quality problem at John Redmond Lake is turbidity. During the last few years, however, inflows and

water levels have declined, creating a scenario where nutrient enrichment can create hypereutrophic conditions. While pollutant sources include both agriculture and municipal point sources, recent drought conditions have also exerted an impact on water quality and use attainment.

Lake Coldwater

Primary water quality problems at this moderate sized recreational lake revolve around nutrient enrichment and inorganic turbidity. Roughly 75% of the watershed is in cultivation, with a watershed/lake ratio of 104. Agriculture comprises the primary source of pollutants. Despite lower water levels in many lakes of the southwestern region of the state, the water level at Lake Coldwater was closer to normal, indicating either good spring flows within the drainage or, perhaps, fortuitous storms passing through the drainage area.

Lake Meade SFL

The primary water quality problem at Lake Meade SFL is related to nutrient enrichment. Despite a large watershed, little of it is likely to be contributory in a hydrologic sense. Spring flows in the vicinity are now largely made up by well discharges. Historically, this lake sported a robust macrophyte community, clear water, and low nutrient levels. Due largely to an increase in both resident waterfowl and hydrologic retention times, the lake has become continually hypereutrophic. Loss of the historic macrophyte community has also contributed to this increase in algal production.

Lake Scott SFL

Primary water quality problems at this lake involve nutrient enrichment and secondary problems related to pH and dissolved oxygen diel changes. Also, spring flows seem to carry a significant level of fluoride, which may reflect passage through volcanic ash layers in the regional soil profiles. Although this lake has a huge drainage area, little of it is likely to be hydrologically contributory. The primary sources of inflow remain the springs at the upstream end of the lake, followed by irrigation return flows entering Ladder Creek and the occasional local storm system. Sources for the extreme nutrient levels observed in the lake are likely due to historic loadings from Ladder Creek, but may also include on-site wastewater management or resident waterfowl as small but significant components. In any event, the lake is continually hypereutrophic while maintaining a large community of the nuisance macrophyte *Myriophyllum spicatum*. Unlike many lakes of the region, very low water levels do not appear to be a factor here, even under drought conditions.

Marion Lake

Water quality problems at Marion Lake are primarily due to nutrient enrichment. The watershed contains about 75% cultivated land and has a watershed/lake ratio of only 19. Despite the low area ratio, the agricultural component provides the source of water quality impairment. While often

more eutrophic than other, similar, large lakes in Kansas, conditions are exacerbated this year due to low water levels.

Mined Land Lake 23 This lake is not part of the statewide permanent monitoring network, but was surveyed this year as part of an investigation into perchlorate contamination from an industrial facility next to Mined Land Lake Unit 23. This lake has extremely elevated nitrate levels (compared to any other standing surface water in Kansas), as well as readily measureable perchlorate levels throughout the waterbody. At the time of the survey, perchlorate levels averaged 1,980 ppb in the whole lake with the most elevated levels closest to the point of contamination.

Mission Lake Primary water quality problems in this moderate sized water supply lake include nutrient enrichment and inorganic turbidity. Secondary problems relate to large diel fluctuations in pH and dissolved oxygen concentration. The watershed of Mission Lake is almost 80% cropland, with a watershed/lake ratio of 73. Agriculture is the primary source of pollutants to Mission Lake. Based on the 2002 survey, this waterbody has experienced the State's highest recorded concentration to date for the relatively new herbicide acetochlor.

Olpe City Lake Primary water quality problems in this smaller recreational lake include nutrient enrichment and inorganic turbidity. The watershed is only about 17% cultivated land, with a small watershed/lake ration of 12. Although having a small total percentage of agricultural land in the drainage, much of it is in close proximity to the lake itself.

Point of Rocks Lake The primary water quality problems at this small recreational lake, in far western Kansas, include nutrient enrichment, pH diel changes, and high fluoride levels. Despite having a reliable connection to local groundwater/watertable, and normally very stable water levels, the water levels were down some in 2002. This may have contributed to the nutrient related problems observed in 2002 as the small watershed does not contain any land uses with a high potential for nutrient runoff. High fluoride levels have been noted here for some time and, as postulated for Lake Scott, may have their origin in volcanic ash deposits in the local geological profile.

St. Jacob's Well The primary water quality problem for this lake small natural lake, in western Kansas, relates to nutrient enrichment. There is also an elevated fluoride level, as has been noted for other western Kansas lakes, which relates to groundwater contributions. As noted in photographs and documents at the Meade County History Museum, St. Jacob's Well once enjoyed a fairly rapid hydrologic flushing rate, very clear water, and overall excellent water quality.

As irrigation has depleted local springs and lowered the regional watertable, this flow has become greatly reduced. The result has been to create a "closed lake" which rarely, if ever, discharges. The watershed of this small lake has no nutrient source to account for the current water quality. It is believed that many years of low/no hydrologic flushing has allowed natural background levels of material deposition to accumulate a high level of nutrients in the water column.

Thayer New City Lake

Primary water quality problems associated with this smaller water supply lake relate to low dissolved oxygen and elevated concentrations of certain metals in the water column. The watershed contains only a few percent of cultivated land, and has a low watershed/lake ratio of 18. Low dissolved oxygen conditions were the result of shallow thermal stratification during 2002. The metal of most concern is copper, which may result from recent attempts at lake management with copper sulphate. Such prophylactic water quality management techniques are discouraged in the majority of water supply lakes in Kansas, but particularly in lakes such as this one which normally has a very high level of water quality.

Taste and Odor/Algal Bloom Investigations During 2002

From January 1, 2002, to March 1, 2003, eleven investigations were undertaken within the auspices of the KDHE Taste & Odor/Algae Bloom Program. The results of these investigation are discussed below. Five of the investigations dealt with fishkills, three primarily with aesthetic complaints, two were related to treatment lagoons, and one was related to finished drinking water quality.

On April 24, 2002, samples were collected by staff of the KDHE Southcentral District Office from a fishkill at a small subdivision lake in Wichita, Kansas. The water of the pond was red in color, and fish of many species and age classes had died. Dissolved oxygen at the time of the midafternoon survey was around 3.0 mg/L. The algae in question could not be identified completely, finally being classed as an unknown species of euglenoid algae. Low dissolved oxygen was the proximal cause of the fishkill, with high algal biomass and nutrient enrichment being the ultimate cause.

On June 7, 2002, staff of the KDHE Southeast District Office collected samples related to a fishkill at New Strawn City Lake. Fish were noted to have gill damage and necrotic spots. The algae community was small and composed of unicellular chlorophyte species. The immediate cause of the fishkill was later determined to be the bacterium Cytophaga (Flexibacter) columnaris, which has been implicated in a number of fishkills in Kansas over the last few years. Such outbreaks are often symptomatic of other environmental stress, such as diel temperature or dissolved oxygen swings.

On June 16, 2002, staff from the KDHE Northcentral District Office collected samples from a residential sandpit lake in Salina, Kansas which was experiencing a fishkill. Algae samples revealed a large community of unicellular green algae. Fish displayed spastic and erratic swimming and turtles also seemed to be effected, leading field staff to believe a toxin was involved rather than a disease. After full examination of fish histological samples (by July), this was also the conclusion of wildlife pathologists at the United States Fish and Wildlife Service. Later algae samples (August, 2002) showed a different community (blue-greens), but still nothing that would explain the apparent toxic effect. Both water and sediment samples were examined for dinoflagellates (like those implicated in the massive fishkill at Melvern Lake in 1990), known to produce symptoms similar to what was observed at this sandpit lake, but none were identified. As of this date, the agent of this toxic effect has not been identified.

On July 25, 2002, staff of the KDHE Southcentral District Office collected samples related to a fishkill at a residential lake in Garden Plain, Kansas. Algae samples indicated a massive blue-green algae community, composed of *Microcystis aeruginosa*, *Aphanizomenon flos-aqua*, and *Cylindrospermopsis sp.* Dissolved oxygen was around 4.0 mg/L by mid morning, suggesting the fishkill could have its proximal cause in either low dissolved oxygen conditions at night, or algal toxicity, or both. It was recommended that residents, especially area children and pets, avoid contact with the lake until the bloom and fishkill were gone.

On August 13, 2002, staff from the KDHE Southcentral District Office collected samples related to a fishkill at a residential lake in Wichita, Kansas. Algae samples revealed a massive community composed mostly of *Anabaena circinalis*. Dissolved oxygen around 8:00 AM was <3.0 mg/L. The proximal cause of the fishkill was identified as low dissolved oxygen at night, algal toxicity, or both. The residents, especially area children and pets, were recommended to avoid contact with the lake until the bloom was gone.

On August 15, 2002, reports from KDHE staff and Lyon County Health Department staff indicated the Neosho River had "turned red" downstream of Americus, Kansas. No fishkill had yet occurred, but the visual condition of the river sparked local concern. Algae samples indicated the red color was due to a massive bloom of *Euglena sp.*, which becomes a common complaint during hot, dry periods of summer in Kansas, when rivers start to become stagnant or pooled (The last instance of the Neosho River becoming pooled in this locale was in 1954.). The bloom itself was not toxic, but suggested nutrient rich, stagnant water existed in the Neosho River. The public and press were informed that fishkills could result if these conditions continued, although no word of further problems was forthcoming.

On August 30, 2002, staff from the KDHE Southcentral District Office collected samples from the Walnut River, east of Udall, Kansas, which had also "turned red" as the Neosho River had earlier done. The cause was the same as for the Neosho River, a *Euglena sp.* bloom, representing stagnant, low flow, nutrient rich conditions in the river.

On September 10, 2002, staff from the KDHE Northeast District Office submitted photographs and algae samples related to an unusual feature in a small residential lake south of Lawrence, Kansas. The lake exhibited a "cloud-like" mass with an unusual yellow-green color. The cause of the color was a bloom of the less common blue-green algae *Coelosphaerium sp.*, which does tend to form very "tight" blooms that float like a cloud in the water column, and possess an atypical (for blue-green algae blooms) yellowish color. Although this species is also known to be able to produce toxins, no fishkill was present. It was recommended the residents simply be informed that they should be aware of the potential for problems and use caution in their recreation at the lake.

On September 24, 2002, KDHE staff submitted algae samples from the Iola sewage treatment lagoons (studied by KDHE staff many years ago due to their water quality conditions) due to what was felt to be "excessive" algae. The algae community was large, even for typical wastewater treatment lagoons, and composed of *Aphanizomenon flos-aqua*. Cell counts were on the order of 1.9 million cells per milliliter, and chlorophyll-a levels exceeded 1,000 ppb. This situation indicated the lagoons were far more productive than the typical lagoon, and represented a cause for concern in the stream they discharge to. Algae associated with lagoon discharges have also been a problem at Eight Mile Creek in southcentral Kansas over the last few years (KDHE, 1999, 2000).

On October 18, 2002, KDHE staff from the Southcentral District Office collected unusual material from the final wastewater treatment lagoon at Haven, Kansas, for analysis. The material coated the rip-rap of the final lagoon cell, and became visible when water levels were lowered as part of normal maintenance work. The material was identified as a "moss animalcule" or bryozoan (*Plumatella fungosa*). These creatures normally do not thrive in such an enriched environment. It was recommended that treatment plant staff simply leave the growths in place as the filter feeding nature of bryozoans might actually aid the overall treatment process.

On February 4, 2003, staff from the KDHE Southcentral District Office submitted samples related to taste and odor complaints in finished drinking water from the city of Winfield, Kansas. Algae samples contained a moderate sized blue-green algae community, composed mainly of *Anabaena sp.*, an algal genera known for "musty/earthy" taste and odor problems. It was concluded that the taste and odor problem was likely related to these algae. It was recommended that settling or removal of the algae intact, prior to any chemical treatment, would provide some benefit.

CONCLUSIONS

The following conclusions are based on the lake monitoring data collected during 2002.

- 1) Trophic state data indicated that only 13% of the lakes surveyed in 2002 had degraded, compared to their historic mean condition (i.e., their trophic state had increased). About 65% showed stable conditions over time, while 22% showed improved trophic state condition.

- 2) Over 50% of the documented water quality impairments in these lakes were associated with high lake trophic status. Other significant problems included low dissolved oxygen and high pH, fluoride, sulphate, and high turbidity. Lake trophic state problems resulted primarily from excessive nutrient inputs from nonpoint sources, although some lakes actually showed improvement due to reduced runoff and pollutant loads over the last two years.
- 3) Twenty-one of the 34 lakes surveyed for pesticides (62%) had detectable levels of agricultural pesticides. As noted in previous years, atrazine was the most frequently detected pesticide. However, detections were below applicable water quality criteria for 2002. A new concern in Kansas is the increasing detection frequency and magnitude of detection for acetochlor. As this herbicide has been marketed as a replacement for atrazine, we may expect this trend to continue.

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LAKE DATA AVAILABILITY

Water quality data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. These data may be requested by writing to the Bureau of Environmental Field Services, KDHE, 1000 Southwest Jackson Ave., Suite 430, Topeka, Kansas 66612-1367.

APPENDIX A: Lake Trophic State Visual Assessments and Lake Reference Condition

INTRODUCTION

The last few years have seen a nationwide movement to accelerate the development of lake/reservoir eutrophication standards. EPA has now developed ecoregional nutrient criteria that the states will be expected to use as guidance for developing their own nutrient criteria, or face having them promulgated by EPA on their behalf (EPA, 1998). There is fairly unanimous scientific opinion that higher lake trophic state does correspond with increasing levels of lake use impairment (e.g.; EPA, 1990; NALMS, 1992; KDHE, 1998a; KDHE, 1998b). A number of states currently have narrative eutrophication criteria in their water quality standards, and several states and Canadian provinces have developed numeric eutrophication criteria (EPA, 1990; NALMS, 1992). A study published in 1989 indicated that about 60% of the states indicate they have a need for numeric eutrophication criteria (Johnson, 1989). A number of recent studies have also indicated a strong connection between increasing lake trophic state and loss of economic revenues from lakes (e.g.; Boyle, et. al., 1997; Jobin, 1997; Pretty et al., 2003).

Kansas has had a narrative eutrophication criterion in its water quality standards for many years. For the last four 305(b) reporting cycles, lake trophic state classification has been used to apply this narrative criterion in assessments of lake use impairment. The validity and value of using non-regulatory numeric criteria to implement a regulatory narrative criterion has been recognized by experts in the area of eutrophication management (Heiskary and Walker, 1988; NALMS, 1992) and is encouraged by the EPA in many of their guidance documents. Table 10 compiles the system that has been used and referenced in recent KDHE documents (KDHE, 1998a, 1998b, 1999, 2000, 2001). This system has been derived largely from the standards developed in other states, incorporating those ideas and concepts that are best suited to our geographic region.

In 1998, KDHE staff began a project to collect data that might provide refined threshold levels for determining lake use impairments based on trophic state and water clarity. The 1998 annual report presented the results of that first effort. During 1999-2002, data collection efforts continued and the combined data has been presented each year in annual program reports. Continuing in that same manner, the combined 1998-2002 data are analyzed and presented in this report. This represents the conclusion of this special project, results of which should prove valuable to all concerned with eutrophication and nutrient related water quality problems.

METHODS

During the summers of 1998-2002, KDHE attempted to verify the suitability of the numeric guidelines presented in Table 10 for assessing lake use impairment by eutrophication. The methodology was developed for use in Minnesota, where lake conditions are described in terms of the frequency, or risk of, nuisance conditions (Heiskary and Walker, 1988). The reader is referred

to that article for an in-depth discussion of procedures. The basic method involves 1) *a-priori* assessments of lake use support, based on visual inspection, 2) correlating visual assessment data with analytical data for trophic state parameters (nutrients, chlorophyll-a, Secchi depth, and non-algal turbidity), 3) conducting a frequency analysis of the data, and 4) using that frequency analysis to develop criteria based on perceived risk levels (<1%, 10%, 25%, etc.).

Three lake uses were assessed for the study conducted in 1998-2002. These were primary contact recreation, secondary contact recreation (formerly designated non-contact recreation), and aesthetic use. This "aesthetic" use should be applied, not only to strict aesthetic uses, but also to other very nutrient sensitive uses such as water supply, or to assessment of the physical appearance of the water. Kansas water quality standards do not recognize an "aesthetic" use for surface waters, unlike some neighboring states such as Nebraska. Nevertheless, the aesthetic quality of lakes does exert an impact on other types of use support and even property values (Boyle, et al., 1997). In Kansas, many housing projects have used their location near a lake to attract buyers. Lowered water quality in these lakes does have an impact on property buyers and property values. "Aesthetic" assessment of the water, for this study, looked for a presence or absence of an overtly visible algae community and inorganic turbidity. Visible "presence" of an algae community should reflect support for water supply uses too because water supply impairments can occur at very low algal biomass (Smith, et al., 2002). While the model for this effort (Heiskary and Walker, 1988) used frequency analysis to derive phosphorus criteria, KDHE chose to derive primary criteria for algal biomass, water clarity, and total phosphorus. The first two criteria should be utilized as the primary indicators of lake use support, although total phosphorus criteria will be of primary importance in both TMDL work and in describing downstream impacts.

While the Minnesota approach utilized only a single visual assessment, focusing on the level of "green" observed in the water, KDHE's study involved two separate assessments, "green" and "brown." These visual assessments relate to impairments resulting from elevated lake trophic state (algal biomass) and reduced levels of water clarity, respectively. In Kansas (and throughout much of the world), traditional water clarity measures, such as Secchi depth and nephelometric turbidity, are influenced more by soil-derived inorganic turbidity than by algae (Davies-Colley, et al., 1993). Given that soil erosion is a major problem in many Kansas watersheds, the use of two visual assessments was deemed valuable. Approximately 7% of Kansas lakes experience chronic inorganic turbidity of sufficient magnitude that it interferes with the normal nutrients-to-algal biomass process. Although impacted by nutrient loads in a different fashion, constituting a distinct sub-population of lakes, they still are impacted and need a method for assessing impacts.

Staff of the Lake and Wetland Monitoring Program conducted visual assessments at each waterbody surveyed during the summers of 1998-2002. This resulted in 3,012 total observational scores being included in the values generated for this report. At each site, staff would first measure Secchi depth. The visual assessments were conducted by examining the color of the water upon the white quarters of the Secchi disk, at the shallower of a depth of one-half the measured Secchi depth or one meter. After examining the color of the water in this manner, plus assessing the overall appearance of the water column, "green" and "brown" scores were assessed by each staff member for each of the three

use categories. The make-up of the field crew was believed to provide a decent cross-section of viewpoints, in that half of those involved had grown up in an urban setting in eastern Kansas while the other half had grown up in a rural western Kansas environment. While this study did not involve a random cross section of the general public, it did provide a valid data base for water quality standards development based on the recommendations of other entities involved in such efforts (Smeltzer and Heiskary, 1990; NALMS, 1992). Assigned scores rarely differed among field staff by more than one unit, demonstrating a general uniformity of perception among informed observers regardless of background. Fully 96% of scores matched exactly, or differed by only one point on a scale of one-to-ten.

Table A1 presents the system for assigning green scores, while Table A2 presents the system for assessing brown scores. In each case, a score of three is meant to represent the onset of minor use impairment (i.e., partial impairment) while a score of five is meant to represent the onset of significant use impairment (i.e., non-support). Only the green or brown quality of the water column was taken into account in assigning scores. The effects of water depth on primary contact recreation, shoreline condition on aesthetic appeal of the lake, lack of a boat ramp on boating, and other such factors were not considered in this exercise.

The frequency/risk potential approach was applied to both sets of scores, for all three uses. The water quality parameters of chlorophyll-a and Secchi depth were used in association with the green visual scores based on a high level of correlation between green visual scores and measured parameters. In a similar fashion, Secchi depth and calculated non-algal turbidity were used in association with brown visual scores based on a high correlation level between brown visual scores and these parameters. Total phosphorus was also examined, in comparison to both green and brown scores, as the original Minnesota study had done. For both brown and green scores, the strength of correlation with total phosphorus was less than for Secchi depth or chlorophyll-a, respectively, but still significant.

The "use hesitation" descriptions in tables A1 and A2 can also be viewed in the following manner. These descriptions apply to either scale, green or brown.

Slight hesitation	Would probably participate in the use at the given location, even if there are other lakes with better water quality nearby, but with reduced enjoyment.
Definite hesitation	Would participate in the use at the current location reluctantly, if at all, even if there were no other lakes nearby with better water quality. If other lakes were near, with better water quality, participation in the use would be moved to the new location despite extra costs in travel or time.
Strong hesitation	Would not participate in the given use at the current location under any circumstances, regardless of any lack of other lakes with better water quality.

Table A1. "Green" score descriptors for primary and secondary contact recreational uses, and for aesthetics and other sensitive uses. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of algae or "green-ness." Other factors, such as waterbody depth or presence of facilities, were not part of the assessment.

Score	Aesthetic Appearance & Sensitive Uses	Primary Contact Recreation	Secondary Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some algae and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading or general recreation.
4			
5	Definite or strong green algae color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced general recreation quality.
6			
7	Very strong green algae color.	Strong hesitation about swimming in or contacting water.	Strong hesitation about wading. Quality of general recreation definitely impaired.
8			
9	Extreme green algae color. Scums and/or odors evident.	Primary contact recreational use enjoyment impossible due to algae levels.	Wading and recreation enjoyment almost impossible due to algae.
10			

Table A2. "Brown" score descriptors for primary and secondary contact recreational uses, and for aesthetics and other sensitive uses. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of turbidity or "brown-ness." Other factors, such as waterbody depth or presence of facilities, were not part of the assessment.

Score	Aesthetic Appearance & Sensitive Uses	Primary Contact Recreation	Secondary Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some turbidity and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading or general recreation.
4			
5	Definite or strong turbidity/brown color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced general recreation quality.
6			
7	Very strong brown turbidity/color.	Strong hesitation about swimming in or contacting water.	Strong hesitation about wading. Quality of general recreation definitely impaired.
8			
9	Extreme brown turbidity/color.	Primary contact recreational use enjoyment impossible due to turbidity levels.	Wading and recreation enjoyment almost impossible due to turbidity.
10			

RESULTS

Combined 1998-2002 Results

"Green" Scores

Three parameters were examined in comparison to the "green" criteria scores, including total phosphorus, chlorophyll-a, and Secchi depth. In the case of Secchi depth, the criteria values discussed in this report section should be applied to lakes that lack overtly visible levels of inorganic turbidity. Table A3 is concerned with lake trophic state (chlorophyll-a levels), Table A4 with in-lake total phosphorus, and Table A5 with Secchi depth.

Table A3. A comparison of use support versus current interpretation of lake trophic state and 1998-2002 *a priori* "green" data. All values are in units of ug/L, or ppb, of chlorophyll-a, rounded to the nearest full unit. The "risks" are the chlorophyll-a threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use.

Lake Use and Support Level	Current Method (trophic state) (chlorophyll-a ppb)	Risk Based Criteria 1998-2002 Green Data	
		<1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	<12	<2	<7
Partial Support	<12	2-6	7-12
Non-Support	>12	>6	>12
Primary Contact Recreational Use			
Full Support	<12	<9	<10
Partial Support	12-20	9	10-23
Non-Support	>20	>9	>23
Secondary Contact Recreational Use			
Full Support	<20	<9	<21
Partial Support	20-56	9-23	21-38
Non-Support	>56	>23	>38

Table A4. A comparison of use support versus current interpretation of in-lake total phosphorus and 1998-2002 *a priori* "green" data. All values are in units of ug/L, or ppb, of total phosphorus. The "risks" are the total phosphorus threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use.

Lake Use and Support Level	Current Method (trophic state) (total phosphorus ppb)*	Risk Based Criteria 1998-2002 Green Data	
		<1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	<25	<15	<15
Partial Support	<25	15	15-27
Non-Support	>25	>15	>27
Primary Contact Recreational Use			
Full Support	<25	<15	<22
Partial Support	25-50	15	22-50
Non-Support	>50	>15	>50
Secondary Contact Recreational Use			
Full Support	<50	<15	<48
Partial Support	50-100	15-50	48-109
Non-Support	>100	>50	>109

* = These values come from the EPA "Red Book."

Table A3 indicates that the use of the distinct trophic state classes for use impairment assessment is a valid method. The greatest discrepancies are in the threshold for non-support of secondary contact recreation, and in the full-support threshold of aesthetic appearance, where current methodology is overly high at a 10% risk level. In these two areas, the current methodology equates with a 30-to-40% and a 55-to-65% risk level, respectively.

Table A4 indicates that, in terms of in-lake total phosphorus, the values published as guidelines for lakes and streams by the EPA back in the 1970s (EPA; 1972, 1976) are very representative of a 10% impairment risk level. The original EPA criteria/goals for total phosphorus were 25 ppb for lakes, 50 ppb for streams entering lakes, and 100 ppb for streams. KDHE has, historically, interpreted these for the Midwest as 25 ppb for open, deep water, 50 ppb for smaller, shallower reservoirs and upper reaches of large reservoirs, and 100 ppb for streams.

Table A5. A comparison of use support versus current interpretation of lake water clarity and 1998-2002 *a priori* "green" data. All values are in units of centimeters, or cm, of Secchi depth. The "risks" are the Secchi depth threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes without overt inorganic turbidity.

Lake Use and Support Level	Current Method (trophic state) (Secchi Depth in cm)*	Risk Based Criteria 1998-2002 Green Data	
		<1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	>100	>216	>216
Partial Support	>100	216	216-151
Non-Support	<100	<216	<151
Primary Contact Recreational Use			
Full Support	>70	>216	>184
Partial Support	>70	216-154	184-92
Non-Support	<70	<154	<92
Secondary Contact Recreational Use			
Full Support	no assessment value	>216	>96
Partial Support	no assessment value	216-91	96-71
Non-Support	no assessment value	<91	<71

* = These Secchi depth values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature.

Table A5 indicates that, in terms of water clarity, Secchi depths currently used as guidelines equate with risk levels much greater than 10%. Therefore, current guideline/water quality goals are likely under-protective of the uses. In countries and regions where water clarity is an actual regulation for swimming use, the value tends to be >100 cm, or "disk visible on the bottom substrate" (Davies-Colley, et al., 1993), which conforms roughly with the 92 and 96 cm threshold values for the 10% risk level for primary contact non-support and secondary contact full support, respectively.

"Brown" Scores

Similar analyses were conducted for the brown visual score data, concerning perceived impairment versus Secchi depth and non-algal turbidity. Table A6 presents the values for Secchi depth, while Table A7 presents similar data for calculated non-algal turbidity.

Table A6. A comparison of use support versus current interpretation of lake water clarity and 1998-2002 *a priori* "brown" data. All values are in units of centimeters, or cm, of Secchi depth. The "risks" are the Secchi depth threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes with overt inorganic turbidity.

Lake Use and Support Level	Current Method (water clarity) (Secchi Depth in cm)*	Risk Based Criteria 1998-2002 Brown Data	
		<1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	>100	>106	>88
Partial Support	>100	106-91	88-66
Non-Support	<100	<91	<66
Primary Contact Recreational Use			
Full Support	>70	>106	>86
Partial Support	>70	106-69	86-54
Non-Support	<70	<69	<54
Secondary Contact Recreational Use			
Full Support	no assessment value	>69	>59
Partial Support	no assessment value	69-56	59-37
Non-Support	no assessment value	<56	<37

* = These Secchi depth values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature.

Table A7. A comparison of use support versus current interpretation of lake water clarity and 1998-2002 *a priori* "brown" data. All values are in units of "per meter," or m^{-1} , of non-algal turbidity. The "risks" are the turbidity threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes with overt inorganic turbidity.

Lake Use and Support Level	Current Method (water clarity) (non-algal turbidity, m^{-1})*	Risk Based Criteria 1998-2002 Brown Data	
		<1%	10%
Aesthetic/Sensitive Uses Physical Appearance Water Supply			
Full Support	<0.40	<0.50	<0.66
Partial Support	0.40-0.70	0.50-0.63	0.66-0.96
Non-Support	>0.70	>0.63	>0.96
Primary Contact Recreational Use			
Full Support	<0.70	<0.50	<0.75
Partial Support	0.70-1.00	0.50-0.87	0.75-1.12
Non-Support	>1.00	>0.87	>1.12
Secondary Contact Recreational Use			
Full Support	no assessment value	<0.63	<1.07
Partial Support	no assessment value	0.63-0.87	1.07-2.18
Non-Support	no assessment value	>0.87	>2.18

* = These non-algal turbidity values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature.

For both sets of data, Tables A6 and A7, the "guideline" values used in the past appear to provide reasonably good threshold criteria for water clarity and turbidity versus recreational and aesthetic use support. These data support the continued use of "best professional judgement" threshold values, for lakes with observable inorganic turbidity.

APPENDIX B: Lake Reference Conditions

INTRODUCTION

In order to determine what reasonable assessment thresholds are, for given waterbody types and beneficial uses, it is necessary to know both what is achievable as well as desirable in terms of water quality. One excellent manner for obtaining this information is to examine so-called “reference” sites. In naturally occurring waterbodies, such as natural lakes, streams, and wetlands, one looks for a waterbody in a setting/watershed possessing the qualities present prior to any human influence. The water quality in such a setting should represent the absolute best one could expect to achieve.

Unfortunately, very few waterbodies currently lack any human influences whatsoever. Therefore, the next best choice for setting the reference condition is to locate “minimally impaired” or “least impaired” waterbodies where human influences are negligible or very low, respectively. These sites then become the surrogate reference condition data set from which to calculate a threshold value for select parameters. They represent the “best” that still exists, and provide a means to examine what is still achievable in terms of water quality.

In Kansas, the great majority of our lakes are artificial lakes. Even so, a good number of them are situated in watersheds with minimal, or low, human influence. Just as in the case of naturally occurring waterbodies, these “minimally/least impacted lakes” allow one to determine what water quality conditions are achievable (EPA 1998b, 2000).

The purpose of this report section is to revisit attempts to quantify lake reference condition in 1998 (KDHE, 1999), and again in 2000, and examine current lake reference thresholds (impact thresholds), specifically for nutrients and trophic condition, calculated from the KDHE Lake and Wetland Program data base. In comparison with the previous risk based assessment thresholds (Appendix A), we can answer the question of whether these risk based numbers represent a water quality condition that is both desirable and possible to achieve.

METHODOLOGY

Two methods are employed here to examine lake reference condition in Kansas. First, lake/watershed units in drainages with minimal/low human influence were selected to form a surrogate reference data set. These lakes had <20% urban and agricultural land in their watersheds and, where there was less than 20%, such land uses were not located primarily along the shoreline or along main inflow streams. In addition, such lakes were not to have documented water quality problems that could be assigned to extreme shallow conditions, bottom feeding fish populations, excessive wind suspension of sediments, or invasive management that would alter water quality significantly. The EPA recommended methodology is to look towards the 75th percentile of the reference site data as the threshold value.

The second method uses a technique called “trisection,” which literally means ranking the data from low to high, dividing it into thirds, then using the third with the best water quality as a surrogate reference data set (EPA 1998b, 2000). Standard methodology is to use the 75th percentile of this surrogate reference data set to define the reference condition threshold, if the data set is a good cross section of conditions across the state or region being analyzed. If low impact sites are rare, it is suggested that the 50th percentile be used, instead, as the threshold value. As the KDHE data set does, generally, approximate a good cross section of water quality condition, the 75th percentile is used to approximate the threshold for “least impacted” while the 50th percentile approximates the threshold for “minimally impacted” lakes. The same cutoffs are applied to the selected “reference” lake data set.

Data used for these calculations are the lake mean values for the period of record 1985-2000 in the case of separate ecoregional values. Analyses including data through 2002 are restricted to just the calculation of statewide threshold values, but are still based on the period of record mean for each lake. Analysis of the data in this fashion reduces bias from different data set sizes for different lakes based on sampling intensity (special project sites) or length of time within the monitoring network.

Ecoregions are identified by the code numbers used by EPA in their level 3 ecoregions. The actual names of these ecoregions are as follows.

- Ecoregion 25 Western High Plains. Includes the western quarter of Kansas. Corresponds to the High Plains Physiographic Region. Combined with Ecoregion 26 in this analysis due to small lake numbers in Ecoregion 26, plus climatic and hydrologic similarities between these two ecoregions.
- Ecoregion 26 Southwestern Table Lands. Includes the southern region of the state west of Wichita and east of Dodge City. Corresponds to the Red Hills Physiographic Region.
- Ecoregion 27 Central Great Plains. Includes a large portion of central Kansas from the Nebraska border south to where the Arkansas River enters Oklahoma.
- Ecoregion 28 Flint Hills. Includes the region from the Oklahoma border to Pottawatomie County, bounded, roughly, east and west by the longitudes of Topeka and Junction City. Corresponds to the physiographic region of the same name. Combined with Ecoregion 29 in this analysis due to small lake numbers in Ecoregion 29, plus similar climatic and hydrologic conditions between these two ecoregions.
- Ecoregion 29 Central Oklahoma/Texas Plains. Comprises the area known as the Chautauqua Hills in southeast Kansas. Corresponds to the Chautauqua Hills Physiographic Region.

- Ecoregion 39 Ozark Highlands. Comprises only the southeastern corner of Cherokee County in Kansas. Therefore, this ecoregion is not included in the analysis. Corresponds to the Ozark Plateau physiographic region.
- Ecoregion 40 Central Irregular Plains. Comprises the eastern quarter of Kansas, with the exception of the northeast corner and the extreme southeastern corner of the state. Corresponds to the Osage Cuestas Physiographic Region.
- Ecoregion 47 Western Cornbelt Plains. This comprises a small portion of northeast Kansas and corresponds to the Glaciated Area Physiographic Region, in part. Although having a small number of lakes for analytical purposes, there is no adjoined ecoregion appropriate to combine it with. Difficulties arising from the small number of sites in this ecoregion will be discussed in various parts of this appendix.

RESULTS

Chlorophyll-a

Chlorophyll-a, as a measure of algal biomass, represents the primary impact of nutrient pollution and eutrophication, aside from general reductions in water clarity and the creation of nuisance and health concerns. Therefore, we shall examine this parameter first in describing lake reference condition in Kansas. Table B1 summarizes data from 1985 through 2000, in terms of individual ecoregions and statewide conditions, as well as statewide conditions for the period of record 1985-2002, for both the trisection method as well as selected reference lakes.

Comparison of the interquartile ranges for statewide threshold values, for both comparing methods and comparing time frames, shows extremely close results. This suggests the Kansas data base does reflect the spectrum of lake types and conditions to be found throughout the state, hence a close correspondence between results from a select surrogate reference data set and the results from the trisection method. Inter-methodology comparisons of individual ecoregions also show very good comparison. In terms of chlorophyll-a and algal biomass, these results suggest there are no significant ecoregional differences to attempt to account for across the state, with the possible lone exception of Ecoregion 47, the Western Cornbelt Plains. These results are very similar to those generated by the EPA Region VII Regional Technical Advisory Group for Nutrient Criteria Development (personal communications), for the four state region of Kansas, Nebraska, Missouri, and Iowa.

As mentioned previously, the Western Cornbelt Plains Ecoregion presented an analytical difficulty related to its extent in Kansas, and a subsequent dearth of lakes to use in any analyses. Also, agricultural activity is so prevalent in this portion of Kansas, it is almost impossible to locate a minimally impacted lake and watershed unit. Using the suggested EPA guidelines for interpreting reference data sets (EPA 1998, 1998b, 2000), the median (50th percentile) value is a better choice for a threshold in this ecoregion. Given the same result for each of the two methods, one might argue

for a separate threshold for Ecoregion 47 and a statewide threshold for everywhere else. However, the problems associated with a smaller data set must also be considered.

Table B1. Descriptive statistics for chlorophyll-a least impacted condition. All values are in ug/L (ppb) and represent the summer time period. "Best" threshold value is highlighted.

	Ecoregion 1985-2000					Statewide 1985-2000	Statewide 1985-2002
	25/26	27	28/29	40	47		
Trisection							
75 th Percentile	8.1	9.8	6.1	8.4	17.1	8.7	9.7
50 th Percentile	8.1	7.7	4.6	7.0	12.7	6.9	7.7
25 th Percentile	6.8	4.5	3.9	5.0	9.8	4.6	5.7
Reference Selections							
75 th Percentile	8.1	8.9	6.9	8.9	12.4	8.9	9.9
50 th Percentile	7.5	6.2	5.4	6.9	10.6	6.8	7.7
25 th Percentile	5.8	4.1	4.6	4.4	8.5	4.1	6.1

It is interesting that the ecoregion with land use conditions closest to those of pre-settlement times, Ecoregions 28/29, the Flint Hills and Chautauqua Hills, has lower chlorophyll-a levels than elsewhere in the state. This region of the state should be viewed as coming closest to describing a "historic" reference condition that could be applied to assessment work in Kansas, the other regions describing a condition closer to what one would call a "least impacted" condition.

Total Phosphorus

Total phosphorus, as a primary limiting nutrient in the majority of Kansas lakes, represents a major focus in controlling and preventing eutrophication. Therefore, we shall now examine this parameter in describing lake reference condition in Kansas. Table B2 summarizes data from 1985 through 2000, in terms of individual ecoregions and statewide conditions, as well as statewide conditions for the period of record 1985-2002, for both the trisection method as well as selected reference lakes.

Comparison of the interquartile ranges for statewide threshold values, for both comparing methods and comparing time frames, shows good results. There were some differences between methodology

in 2000, but this seems to have disappeared with the addition of the two most recent years of data. Inter-methodology comparisons of individual ecoregions also show very good comparison for the most part. In terms of total phosphorus, as a primary nutrient of concern, these results suggest there are no significant ecoregional differences to attempt to account for across the state, with the possible exceptions of Ecoregion 27, the Central Great Plains, and Ecoregion 47, the Western Cornbelt Plains. Differences in Ecoregion 47 are less pronounced than they were for chlorophyll-a, but greater in Ecoregion 27.

Table B2. Descriptive statistics for total phosphorus least impacted condition. All values are in ug/L (ppb) and represent the summer time period. "Best" threshold value is highlighted.

	Ecoregion 1985-2000					Statewide 1985-2000	Statewide 1985-2002
	25/26	27	28/29	40	47		
Trisection							
75 th Percentile	26	50	21	25	29	27	30
50 th Percentile	20	35	20	20	25	21	23
25 th Percentile	15	20	5	15	23	16	18
Reference Selections							
75 th Percentile	26	34	21	20	25	21	30
50 th Percentile	20	20	20	19	24	20	21
25 th Percentile	15	14	5	10	22	11	17

These two ecoregions in Kansas (27 and 47), as mentioned before, combine high amounts of cultivated land with sufficient average rainfall and runoff. As such, they present the greatest area of difficulty for identifying lakes and watersheds in a relatively unimpacted state. These results are also very similar to those generated by the EPA Region VII Regional Technical Advisory Group for Nutrient Criteria Development (personal communications), for the four state region of Kansas, Nebraska, Missouri, and Iowa. Using the suggested EPA guidelines for interpreting reference data sets (EPA 1998, 1998b, 2000), the median (50th percentile) value is a better choice for a "least impacted" threshold in Ecoregions 27 and 47, given the rarity of truly unimpacted lake/watershed units.

Total Nitrogen

Total nitrogen is the primary nutrient controlling eutrophication in a small percentage of Kansas lakes. Although not as universal a limiting factor, it should be considered in the determination of lake reference conditions. Table B3 summarizes data from 1985 through 2000, in terms of individual ecoregions and statewide conditions, for both the trisection method as well as selected reference lakes. No attempt was made to further update this parameter beyond year 2000 data.

Comparison of the interquartile ranges for statewide threshold values shows varied results. Total nitrogen data is hampered by three additional confounding factors, which are not significant for total phosphorus or chlorophyll-a. First, total nitrogen calculations are relatively new for the lake and wetland network, reaching back only to 1998. This reduces the number of lakes that meet both "surrogate reference lake" criteria and also have sufficient data. Second, nitrogen has a significant atmospheric component in its ecological cycling. As such, nitrogen can enter a lake in significant amounts without any consideration of the immediate watershed condition. Third, there is also a significant groundwater source for nitrogen in terms of baseflow and springs in agricultural areas, which could, in theory, cross watershed boundaries. In terms of total nitrogen, these results suggest significant ecoregional differences which reflect the general amount of cultivated land and the regional hydrology working in concert.

Table B3. Descriptive statistics for total nitrogen least impacted condition. All values are in ug/L (ppb) and represent the summer time period. "Best" threshold value is highlighted.

	Ecoregion 1985-2000					Statewide 1985-2000
	25/26	27	28/29	40	47	
Trisection						
75 th Percentile	601	800	245	557	657	591
50 th Percentile	474	695	138	405	627	406
25 th Percentile	347	588	80	248	626	234
Reference Selections						
75 th Percentile	1273	839	609	1011	671	819
50 th Percentile	925	800	406	628	656	625
25 th Percentile	601	764	112	282	640	266

In terms of the trisection methodology, Ecoregions 25/26, 40, and 47 seem to match statewide values fairly well. Once again, however, Ecoregions 27 and 47 have a general lack of truly unimpacted sites. Also, the Flint Hills region (Ecoregion 28) would seem to have the best overall total nitrogen values, reflective of the preponderance of native grassland in the region. Again, based on the recommended protocols, the 75th percentile should be the preferred choice to define the threshold, with the exception of Ecoregions 27 and 47, where even “least impacted” sites become rare.

A comparison of trisection methodology with selected reference lakes provided very good results for chlorophyll-a and total phosphorus. Such is not the case for total nitrogen, for all the reasons previously indicated in this report section. In terms of total nitrogen, it is concluded that sites “least impacted” for phosphorus and chlorophyll-a may not also show least impacted conditions for other parameters due to atmospheric and groundwater related deposition. In the case of Ecoregion 47, the selected reference lakes with total nitrogen data number only two, which is really not adequate to calculate the interquartile range with any confidence (hence, no shaded value). Even comparing the selected surrogate reference lake ecoregional median values to trisection 75th percentiles provides only somewhat adequate comparisons. The recommendation in this case would be to default to the “whole population” trisection method for defining total nitrogen thresholds, given multiple difficulties with identifying “minimally impacted/unimpacted” sites for this parameter.

Comparison to Risk Based Threshold Values

If these “minimally impacted” or “least impacted” thresholds define what is currently obtainable in terms of water quality condition, how do these compare to the thresholds that are “desirable,” which were presented in Appendix A? If the risk based thresholds are sound, they should be at, or above, what an examination of minimally and least impacted condition says is obtainable. The remainder of this appendix will compare the impact thresholds to the risk based use support thresholds for eutrophication and nutrient sensitive uses for total phosphorus and chlorophyll-a.

Table B4 presents the comparisons of impact thresholds against risk based use support thresholds, from appendix A, for nutrient sensitive uses (water supply or aesthetics). For both chlorophyll-a and total phosphorus, impact thresholds tend to fall between the full-to-partial support and partial-to-non support thresholds at the 10% risk level. However, surrogate historic reference condition chlorophyll-a thresholds do fall below both risk based numbers, suggesting attainment is at least possible. In all, the 10% risk thresholds for the most nutrient sensitive uses could be met under ideal conditions for full support, and could be met for partial support under typical least impacted conditions.

Table B5 presents comparisons of impact thresholds against risk based use support thresholds for primary contact recreation. For both chlorophyll-a and total phosphorus, surrogate historic reference condition and least impacted condition thresholds tend to fall below the full-to-partial use support threshold at the 10% risk level. Only in the case of the least impacted condition for total phosphorus does the value fall between the two risk based threshold numbers. This implies that full support at

the 10% risk level is achievable generally for primary contact recreation, without the lake needing to be in pristine settings to achieve full support of the use.

Table B4. Risk based use support thresholds for chlorophyll-a and total phosphorus compared to impact thresholds for Kansas lakes. The risk level for use support thresholds is 10% (i.e., 10% or more people would perceive an impairment at the stated level) and refers to nutrient sensitive uses such as water supply and aesthetic related uses. Impact thresholds include the Flint/Chautauqua Hills Regions as surrogate for historic reference condition, while statewide numbers reflect contemporary “least impacted” (75th percentile) and “minimally impacted” (50th percentile) condition.

Nutrient Sensitive Uses (Water Supply, etc.)	Chlorophyll-a	Total Phosphorus
Threshold From Full to Partial Use Support	7.0	15
Threshold From Partial to Non Support of Use	12.0	27
Surrogate Historic Reference Condition Threshold (Ecoregions 28 and 29)		
Trisection Method		
75 th Percentile Value	6.1	21
50 th Percentile Value	4.6	20
Selected Reference Site Method		
75 th Percentile	6.9	21
50 th Percentile	5.4	20
Least/Minimally Impacted Condition Threshold (Statewide)		
Trisection Method		
75 th Percentile Value	9.7	30
50 th Percentile Value	7.7	23
Selected Reference Site Method		
75 th Percentile	9.9	30
50 th Percentile	7.7	21

Table B5. Risk based use support thresholds for chlorophyll-a and total phosphorus compared to impact thresholds for Kansas lakes. The risk level for use support thresholds is 10% (i.e., 10% or more people would perceive an impairment at the stated level) and refers to primary contact recreation use. Impact thresholds include the Flint/Chautauqua Hills Regions as surrogate for historic reference condition, while statewide numbers reflect contemporary “least impacted” (75th percentile) and “minimally impacted” (50th percentile) condition.

Primary Contact Recreation Use	Chlorophyll-a	Total Phosphorus
Threshold From Full to Partial Use Support	10.0	22
Threshold From Partial to Non Support of Use	23.0	50
Surrogate Historic Reference Condition Threshold (Ecoregions 28 and 29)		
Trisection Method		
75 th Percentile Value	6.1	21
50 th Percentile Value	4.6	20
Selected Reference Site Method		
75 th Percentile	6.9	21
50 th Percentile	5.4	20
Least/Minimally Impacted Condition Threshold (Statewide)		
Trisection Method		
75 th Percentile Value	9.7	30
50 th Percentile Value	7.7	23
Selected Reference Site Method		
75 th Percentile	9.9	30
50 th Percentile	7.7	21

Table B6 presents the final of the three comparisons between impact thresholds and risk based use support thresholds. For secondary contact recreation, use support thresholds, at the 10% risk level, are far above the impact threshold values. This implies attaining full support for secondary contact recreation should be relatively easy in most Kansas lakes.

Conclusion

In summary, both the “minimally impacted” and “least impacted” (i.e., impact thresholds) nutrient/trophic state condition for Kansas lakes describe a system on, or just past, the mesotrophic/eutrophic boundary. The glimpse of potential historic reference conditions, which the Flint Hills region provides, indicates Kansas lakes would have the expectation of being firmly mesotrophic in character under natural land use scenarios. Under either set of conditions (historic reference or least impacted threshold), full support of all but the most critically nutrient sensitive uses would be expected.

A comparison to nutrient/trophic state use support thresholds, derived to represent a 10% risk of impairment at each stated threshold value, strongly suggests the majority of Kansas lakes could attain full use support for all designated uses under least impacted conditions. Least impacted conditions could be achieved either by lowering the extent of more polluting land use activities in the watershed (approximating the conditions of the selected “reference” waterbodies) or through the application of best management practices designed to control and reduce nutrient pollution in runoff and infiltration. Nutrient pollution and eutrophication are widespread and significant water quality problems for waterbodies throughout the nation (EPA 1998b, 2000), however, their impacts on beneficial uses can be successfully addressed in the context of existing environmental protection programs.

Table B6. Risk based use support thresholds for chlorophyll-a and total phosphorus compared to impact condition thresholds for Kansas lakes. The risk level for use support thresholds is 10% (i.e., 10% or more people would perceive an impairment at the stated level) and refers to secondary contact recreation use. Impact thresholds include the Flint/Chautauqua Hills Regions as surrogate for historic reference condition, while statewide numbers reflect contemporary “least impacted” (75th percentile) and “minimally impacted” (50th percentile) condition.

Secondary Contact Recreation Use	Chlorophyll-a	Total Phosphorus
Threshold From Full to Partial Use Support	21.0	48
Threshold From Partial to Non Support of Use	38.0	109
Surrogate Historic Reference Condition Threshold (Ecoregions 28 and 29)		
Trisection Method		
75 th Percentile Value	6.1	21
50 th Percentile Value	4.6	20
Selected Reference Site Method		
75 th Percentile	6.9	21
50 th Percentile	5.4	20
Least/Minimally Impacted Condition Threshold (Statewide)		
Trisection Method		
75 th Percentile Value	9.7	30
50 th Percentile Value	7.7	23
Selected Reference Site Method		
75 th Percentile	9.9	30
50 th Percentile	7.7	21

APPENDIX C: A Trophic State Survey of the Mined Land Recreation Area Lakes

INTRODUCTION

During the past two years, KDHE staff have been conducting use attainability surveys on a variety of lakes and streams throughout the state in order to document existing and potential beneficial uses for each waterbody. In September of 2002, all 45 management units at the Mined Land Recreation Area in southeast Kansas received use attainability surveys. These surveys provided an additional opportunity to examine, in some brief manner, the range of trophic state conditions to be found among the lakes in this public recreation area. Given the time of the summer, and the recent two years of drought condition, the results of this synoptic survey of trophic state conditions could be viewed as reflecting worst case conditions in terms of overall water quality. The majority of these lakes have very small watersheds with fairly unpolluting (in terms of nutrients) land uses, relatively high interaction with local groundwater, and are generally of good water quality. Despite very low water levels in many areas of the state, water levels at these lakes, in general, were not excessively low but tended to be slightly below normal pool elevation.

METHODOLOGY

At each lake, typically at the boat ramps, surface water samples were collected for chlorophyll-a analysis at approximately 3.0 meters from the shore using a pole sampler or steel pail. Where possible, Secchi disk measurements were made (from piers and docks, or similar structures). Where Secchi disk measurements were made under less than ideal condition (such as from the shoreline), they were recorded as a "greater than" estimate. Shoreline estimates for Secchi disk are possible at many of these lakes due to the relatively steep drop off. While some management units have several lakes (often loosely connected physically and hydrologically), all data were collected at the largest accessible waterbody within a given unit and used as an integrated measure for the unit as a whole. All field work was conducted during the first week of September, 2002.

RESULTS

Physical Descriptions

The lakes of the Mined Land Recreation Area can be viewed as representing a unique setting in Kansas due to the sheer number of lakes in a relatively small area. Yet, they possess many similarities to smaller lakes elsewhere in the state, making them useful for describing water quality expectations under fairly unimpacted conditions. Although their creation via surface coal mining was hardly natural, many years have passed since these lakes came into being. Through the processes of lake aging, most have become circumneutral in acidity. The only water quality signatures, relating back to their origin, an elevated sulphate and hardness levels in the water column

compared to other lakes in the region. Table C1 compiles some basic descriptive information regarding the Mined Land Recreation Area lakes compared to statewide numbers.

Table C1. Basic lake and watershed physical data for lakes in the Mined Land Recreation Area and lakes and wetlands statewide. Statewide data are based on 226 lakes and wetlands throughout the state, which includes many smaller lakes not part of the Lake and Wetland Monitoring Program network. For the Mined Land Recreation Area, watershed and depth related data are based on the eight Mined Land Lakes within the Lake and Wetland Monitoring Program sampling network. Water depths based on these eight lakes, if extrapolated to the other lakes in the Mined Land Recreation Area, may prove to be exaggerated. Values given are medians, with the 25th and 75th percentile (interquartile range) given in parentheses.

Feature	Statewide	Mined Land Area
Lake Area (acres)	45 (10-155)	28 (14-50)
Watershed Area (acres)	1,349 (243-4,708)	111 (73-177)
Watershed/Lake Area Ratio	29 (14-77)	7 (6-8)
Portion of Watershed as Agricultural and Urban Land (%)	35 (10-77)	<1 (0-1)
Maximum Depth (m)	4.0 (2.5-8.0)	9.8 (6.8-13.9)
Mean Depth (m)	1.7 (1.0-3.2)	5.2 (3.7-7.3)

Mined Land Recreation Area lakes tend to be slightly smaller, and have smaller drainages, than do lakes elsewhere throughout the state. Mined Land Lakes also tend to have watersheds with far less in the way of pollutant generating land uses, although some individual management units are next to industrial facilities. Mined Land Lakes also tend to be deeper than most lakes of their size elsewhere in Kansas, but the actual values calculated in Table C1 may be somewhat exaggerated because they are based only on sites included in the sampling network, which are partially selected due to their size and boat accessibility. Despite some physical differences, Mined Land Lakes are comparable to Kansas lakes in general. First, like most Kansas lakes, they were created through human activity. Second, hydrologic routing is similar to natural lakes, and most other smaller Kansas lakes, in that discharge is at the surface. Third, the differences in lake size are probably not statistically significant (based on interquartile box overlap). In most respects, lakes in the Mined Land Recreation Area have more similarities than differences when compared to the majority of smaller Kansas lakes.

Trophic State Data

Table C2 presents the data collected during early September, 2002, from the 45 management units in the Mined Land Recreation Area.

Table C2. Trophic state data from the 45 management units within the Mined Land Recreation area. All data was collected during the first week of September, 2002. Data comes from the largest accessible lake within each unit.

Lake Unit	Grouping	Chlorophyll-a (ppb)	Secchi Depth (cm)
1	Pittsburg	38.20	35
2	Pittsburg	not sampled	about 50
3	Pittsburg	3.75	200
4	Pittsburg	2.70	>400
5	Pittsburg	8.70	150
6	Pittsburg	36.30	80
7	Pittsburg	5.00	>200
8	Pittsburg	9.20	140
9	Scammon	3.75	100
10	Scammon	not sampled	>200
11	Scammon	1.95	>400
12	Scammon	2.10	>300
13	Scammon	2.25	>300
14	Scammon	not sampled	poor access
15	Scammon	3.00	>400
16	Scammon	no water present in unit	no water present in unit
17	West Mineral	0.45	>250
18	West Mineral	0.90	>350
19	West Mineral	14.95	>100
20	West Mineral	5.90	>200
21	West Mineral	1.50	>300
22	West Mineral	5.15	>450
23	West Mineral	5.55	>450

Lake Unit	Grouping	Chlorophyll-a (ppb)	Secchi Depth (cm)
24	West Mineral	24.35	70
25	West Mineral	41.05	20
26	Cherokee	15.65	110
27	West Mineral	3.60	>300
28	West Mineral	not sampled	too low
29	West Mineral	9.05	>150
30	West Mineral	1.80	>400
31	West Mineral	18.60	60
32	West Mineral	6.35	>200
33	West Mineral	1.80	>200
34	West Mineral	17.75	80
35	West Mineral	29.65	60
36	West Mineral	48.80	25
37	West Mineral	3.00	>150
38	West Mineral	2.25	>400
39	West Mineral	0.60	>450
40	West Mineral	27.35	60
41	West Mineral	48.60	60
42	West Mineral	1.50	>450
43	West Mineral	1.65	>250
44	West Mineral	8.80	50
45	West Mineral	9.60	>200

As can be seen from the raw data in Table C2, the lakes of the Mined Land Recreation Area describe a wide array of trophic state and water clarity conditions, ranging from turbid and productive, to very clear with low algal production, to very clear with higher algal production. Missing from this population of lakes are turbid systems (argillotrophic systems) with algal production suppressed by light limitation.

Table C3 presents data comparing the major geographic clusters of Mined Land Lakes to the total Mined Land Recreation Area, for both trophic state and water clarity. Pittsburg area lakes tended to be very slightly more productive and slightly less clear, while Scammon area lakes tended to have higher water clarity and be less productive of phytoplankton, both as compared to the whole population.

Table C3. Comparisons of geographic clusters of Mined Land Lakes, in terms of trophic status and water clarity in early September, 2002. Values given are the median, with the 25th and 75th percentile values (the interquartile range) given in parentheses.

Group	Chlorophyll-a (ppb)	Trophic State	Secchi Depth (cm)	Water Clarity
Pittsburg	8.70 (4.38 to 22.75)	Slightly Eutrophic (Mesotrophic to Very Eutrophic)	>145 (73 to >200)	Clear (Slightly Turbid to Very Clear)
Scammon/Cherokee	2.63 (2.14 to 3.56)	Mesotrophic (Oligomesotrophic to Mesotrophic)	>300 (>155 to >350)	Extremely Clear (Clear to Extremely Clear)
West Mineral	5.90 (1.80 to 18.18)	Mesotrophic (Oligomesotrophic to Eutrophic)	>200 (65 to >325)	Very Clear (Slightly Turbid to Extremely Clear)
Whole Population	5.35 (2.21 to 16.18)	Mesotrophic (Oligomesotrophic to Eutrophic)	>200 (80 to >300)	Very Clear (Slightly Turbid to Extremely Clear)

As shown in Table C3, lakes within the Mined Land Recreation Area tend towards high water clarity and relatively low phytoplankton standing crops (lower trophic status). This is entirely consistent with their current watershed conditions and our general understanding of nutrient dynamics. In all, the majority of these lakes are in an ideal nutrient/trophic state/clarity condition for all forms of recreation and aquatic life support. As far as low pH concerns, given the origins of these lakes, very few seem to still have pH values much below 7.0. The majority of those that do have pH values on the acid side of the scale are in the Scammon area, which was known to have a higher sulphur content to the coal seams than other surrounding areas (KDHE, 1993) and, subsequently, would be expected to have more acidity concerns. During the synoptic pH survey conducted by KDHE in 1993, only 16% of the lakes sampled had pH values between 6.0 and 6.9. Only 6% had pH values <6.0, with the lowest pH value being 4.2 units.

The majority of these lakes have fairly low phytoplankton production but have robust macrophyte communities with high species diversity. In most, the macrophyte community could be described as mesotrophic to eutrophic, indicating ample primary and secondary benthic production to fuel fisheries while maintaining excellent conditions for recreation and aesthetic appeal (Schneider and Melzer, 2003). None of the macrophyte communities observed over the years at these lakes could be termed “excessive;” rather, they provide what might be regarded as desirable or optimal aquatic habitat conditions.

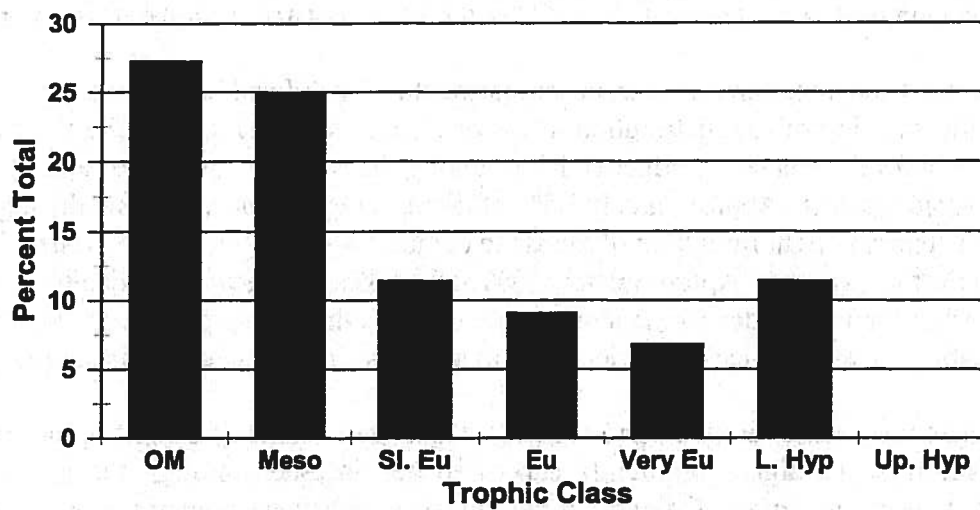
Figure C1 presents the distribution of trophic state classes within the Mined Land Recreation Area, while Figure C2 presents a comparison to lakes statewide. Graph C1 reflects the data collected during this synoptic survey. The statewide graph (C2) reflects historic mean conditions and includes only those Mined Land Lake Units that are part of the routine ambient monitoring network (seven total). The oligomesotrophic group in Graph C2 is, therefore, not a reflection of this synoptic survey.

Some of the most apparent items of note, in comparing the Mined Land Lakes to the state as a whole, include 1) the skewing of the distribution to lower trophic state classes among the Mined Land Lakes, 2) the lack of extremely productive lakes among the Mined Land Lakes, and 3) the lack of extremely turbid systems. Approximately 3.8% of lakes, statewide, have chronically high turbidity that promotes extreme light limitation of the algae community (argillotrophy). None of the Mined Land Lakes fits that category. Approximately 10% of the lakes in the statewide database do not have trophic state data for making determinations. Approximately the same proportion (9%) of the Mined Land Recreation Area units lack sufficient data to assign a trophic state classification.

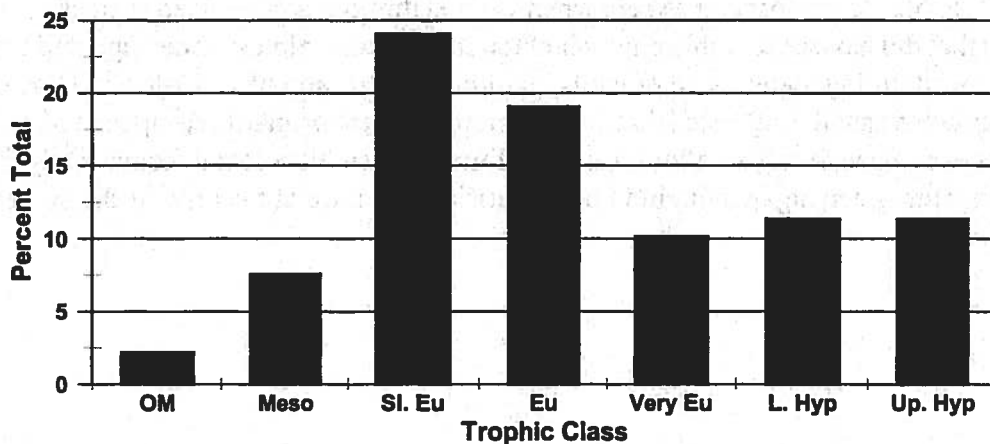
Although algae taxonomic samples were not collected as part of this synoptic trophic state survey, the composition of the algae community can often be discerned through the gross color and appearance of the water column. Color often can suggest which algae group is the prominent feature of the system, while the presence of floating colonies often identifies blue-green algae down to family or genera. In most of these lakes, phytoplankton were in low enough amount to prevent any visual assessment of dominant algal groups. In most cases, algal chlorophyll-a less than about 4-6 ppb is not “visible” to an observer except when viewed through a fairly deep expanse of water. For those lakes that did have observable phytoplankton in the water, almost none appeared to have blue-green algae or dinoflagellates as an obvious feature of the community. Color and “patchiness” in the water columns usually suggested that the communities were primarily composed of various green (chlorophycean) algae, likely smaller flagellated forms and small colonial forms. Only for Units 22 and 23 were blue-green algae thought to be a significant feature at the time of the surveys.

Figure C1 and C2. The first graph depicts the distribution of trophic state classifications within the Mined Land Recreation area, while the second depicts Kansas lakes as a whole. The abbreviations are as follows: OM = oligomesotrophic (chlorophyll-a <2.5 ppb), Meso = mesotrophic (chlorophyll-a between 2.5 and 7.2 ppb), Sl. Eu = slightly eutrophic (chlorophyll-a between 7.2 and 12.0 ppb), Eu = eutrophic (chlorophyll-a between 12.0 and 20.0 ppb), Very Eu = very eutrophic (chlorophyll-a between 20.0 and 30.0 ppb), L. Hyp = lower hypereutrophic (chlorophyll-a between 30.0 and 56.0 ppb), and Up. Hyp = upper hypereutrophic (chlorophyll-a \geq 56.0 ppb).

Mined Land Lakes



Statewide Lakes



Limiting Factors

Although a complete suite of nutrient samples were not collected at each Mined Land Lake, some tentative conclusions about nutrient status could be reached based on chlorophyll-a and Secchi depth data. Limiting factor determinations are assigned to three general categories; light, nutrients (including trace nutrients), and "other factors." Other factors include potential limitation due to biological interactions with the macrophyte or zooplankton communities, or hydrologic conditions, as examples.

Limitation of the phytoplankton community by nutrients (41%), and nutrients combined with biological interactions (25%), comprised the majority of determinations. For at least a few of these systems, iron may become a limiting nutrient at times, as was evidenced in Units 22 and 23 during a special investigation conducted in late August, 2002.

Light limitation, whether in combination with other features of the system or not, was found to have some controlling capacity in 18% of these lakes. However, the finding of light being a limiting factor does not have the same meaning, in terms of visual turbidity of the system, as it might elsewhere in the state. Although the metrics suggest light can become limiting in some of these water columns, it is more a result of the level of clarity combined with total water column depth rather than gross levels of inorganic turbidity. About 36% of these lakes showed (through comparisons of Carlson TSI scores) small particles to exert some influence in the water column (whether inorganic or biological). In only two lakes (4.5%), Units 22 and 23, did large particles (blue-green algae colonies or large flagellate cells) in the water column play a significant role in terms of light attenuation. In this unique instance, the lakes in Units 22 and 23 were part of a special investigation undertaken only a couple weeks prior to this synoptic survey. Algae samples taken as part of this special investigation confirmed the presence of colonial blue-greens as a significant component in the algae community of both lakes.

Biological interactions, of possibly varied nature, seemed to be the primary limiting factor in 16% of lakes in the Mined Land Recreation Area. This is much greater than normally seen in the statewide population of lakes. Considering the relatively "lush" nature of submersed aquatic plant communities among the Mined Land Lakes, in terms of both abundance and species richness (compared to the typical absence of macrophytes in lakes around the state), a higher percentage is to be expected. In fact, these lakes provide a vivid example of the value of macrophyte communities in improving and maintaining lakes for recreation and aquatic life support functions. In addition to providing competition to phytoplankton for nutrients, macrophytes provide varied habitat for fish, help promote higher levels of water clarity, and add to the overall aesthetic appeal of a lake for many forms of recreational use.

CONCLUSION

The synoptic survey of lakes in the Mined Land Recreation Area, conducted during early September, 2002, provided evidence of an exceptional water resource in Kansas, in terms of both recreational potential and as habitat for a wide range of aquatic and semiaquatic life. Lakes within this State managed facility provide a diversity of trophic state conditions and aesthetic experiences to visitors, campers, and anglers alike, while maintaining exceptional levels of aquatic diversity. Lakes within the Mined Land Recreation Area are also valuable in provided a glimpse of potential water quality conditions under natural plant cover conditions in small watersheds. Protecting this public recreational water resource from outside impacts and pollution, and the preservation of its current physical features and water quality, should be given a high priority in terms of statewide conservation management goals.